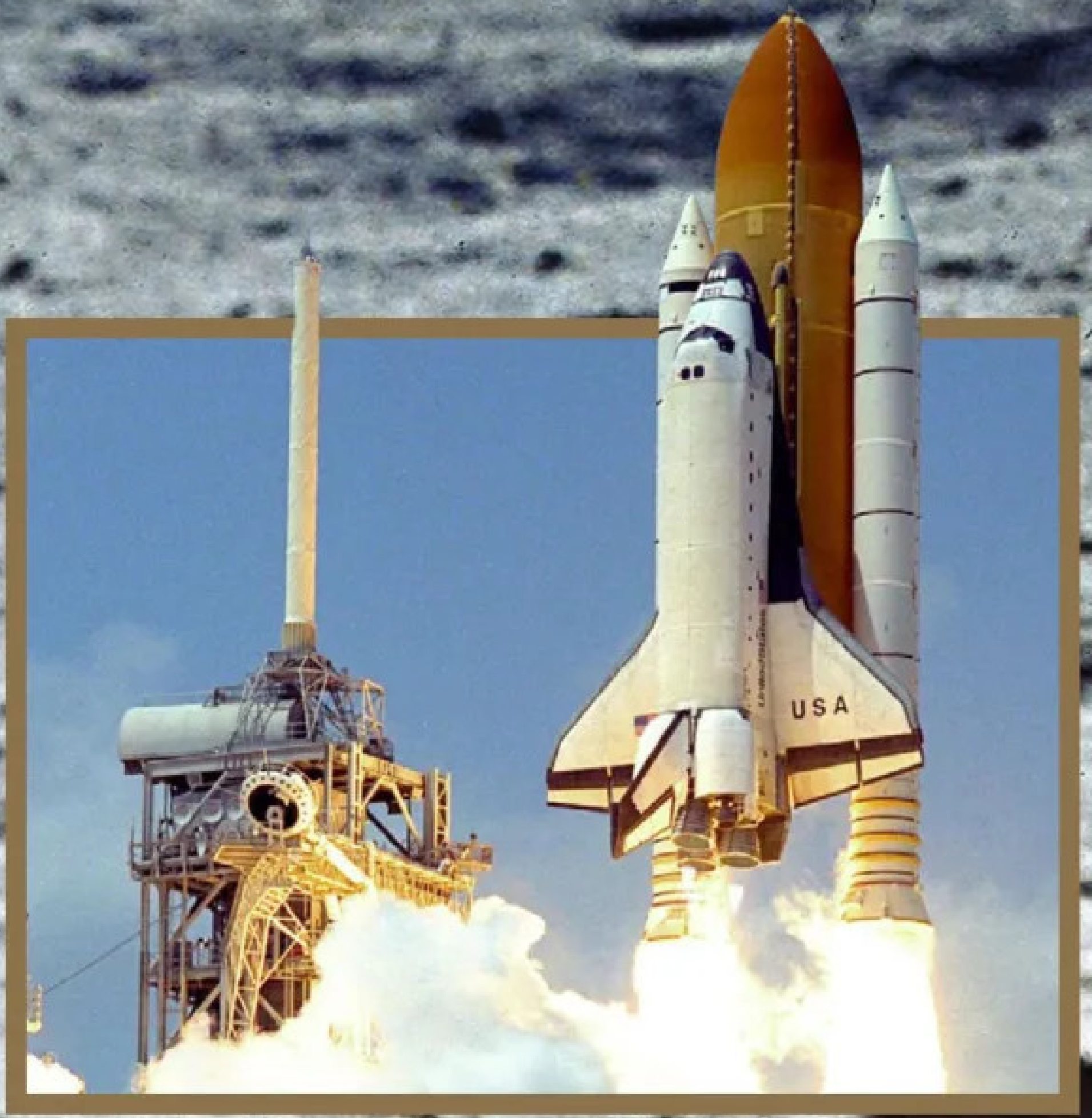
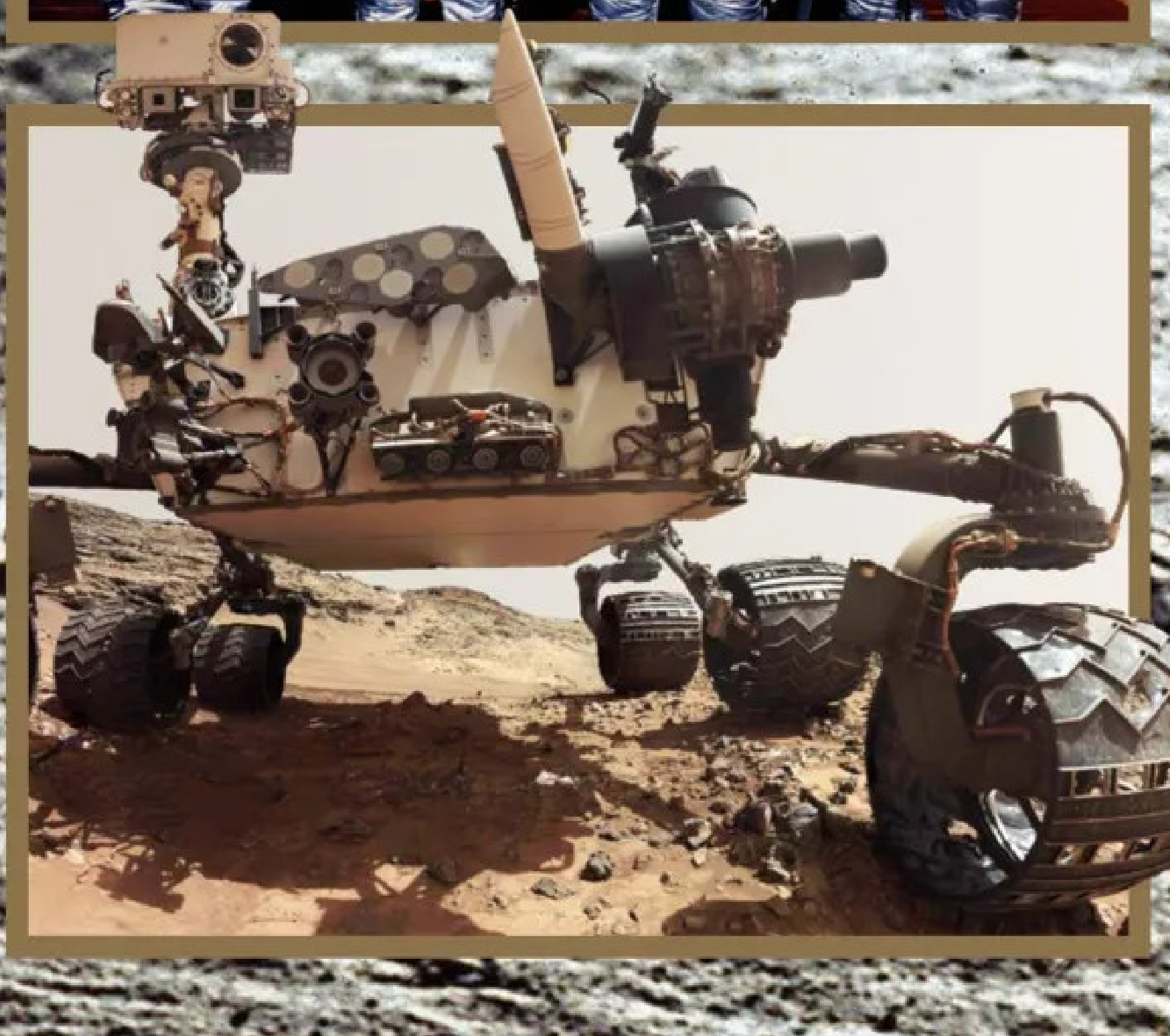
NEW

# HISTORY OF NASA

THE FASCINATING STORY OF THE ICONIC AMERICAN SPACE AGENCY

CELEBRATE OVER 60 YEARS OF EXPLORING SPACE





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# Welcome to HISTORY OF NASA

On 29 July 1958, President Dwight D Eisenhower signed into US law a federal statute that would change the universe forever. The terms of the National Aeronautics and Space Act, fuelled by the president's distrust of what, three years later, he would come to call 'the military-industrial complex', set out objectives for the creation of a civilian space agency, one that was not controlled by generals, intelligence officials or businessmen, but by scientists; whose aim was not war, but peace. NASA was born.

In the decades since its inception, NASA has been responsible for some of the most important advances humankind has ever made. It has left the footprints of astronauts on our Moon and sent spacecraft beyond the limits of our Solar System. Its Mars rovers, controlled remotely by human drivers here on Earth, search for life on the plains of the Red Planet; its Hubble Space Telescope looks back through time and space towards the very beginning of the universe itself. No other organisation has ever gone beyond the boundaries of nationality and politics to embody humanity's curiosity, vision and ambition in the way that NASA has. It has shown us what it is possible to achieve.

This is the story of how and why it was created, of its greatest triumphs and darkest days, of the times it exceeded all possible hopes and the times when those hopes were utterly crushed. It's a story of adventure, and heroism, and resourcefulness, and of the greatest achievements in all of human history. Most of all, though, this is the story of how, over six decades, the iconic agency has consistently and tirelessly devoted itself to its founding principle – the firmly held belief that "activities in space should be devoted to peaceful purposes for the benefit of all humankind". This is the history of NASA.

# Contents

## The Space Race

6 NASA takes flight

12 America's secret space race

16 Rise of the Space Age

22 The beginning of NASA: Project Mercury

26 Learning to fly: Project Gemini

30 Gemini 8: Mission abort

## Moonshot

32 Project Apollo

34 Apollo 1

36 Apollo 7

40 Apollo 8

42 Apollo 9

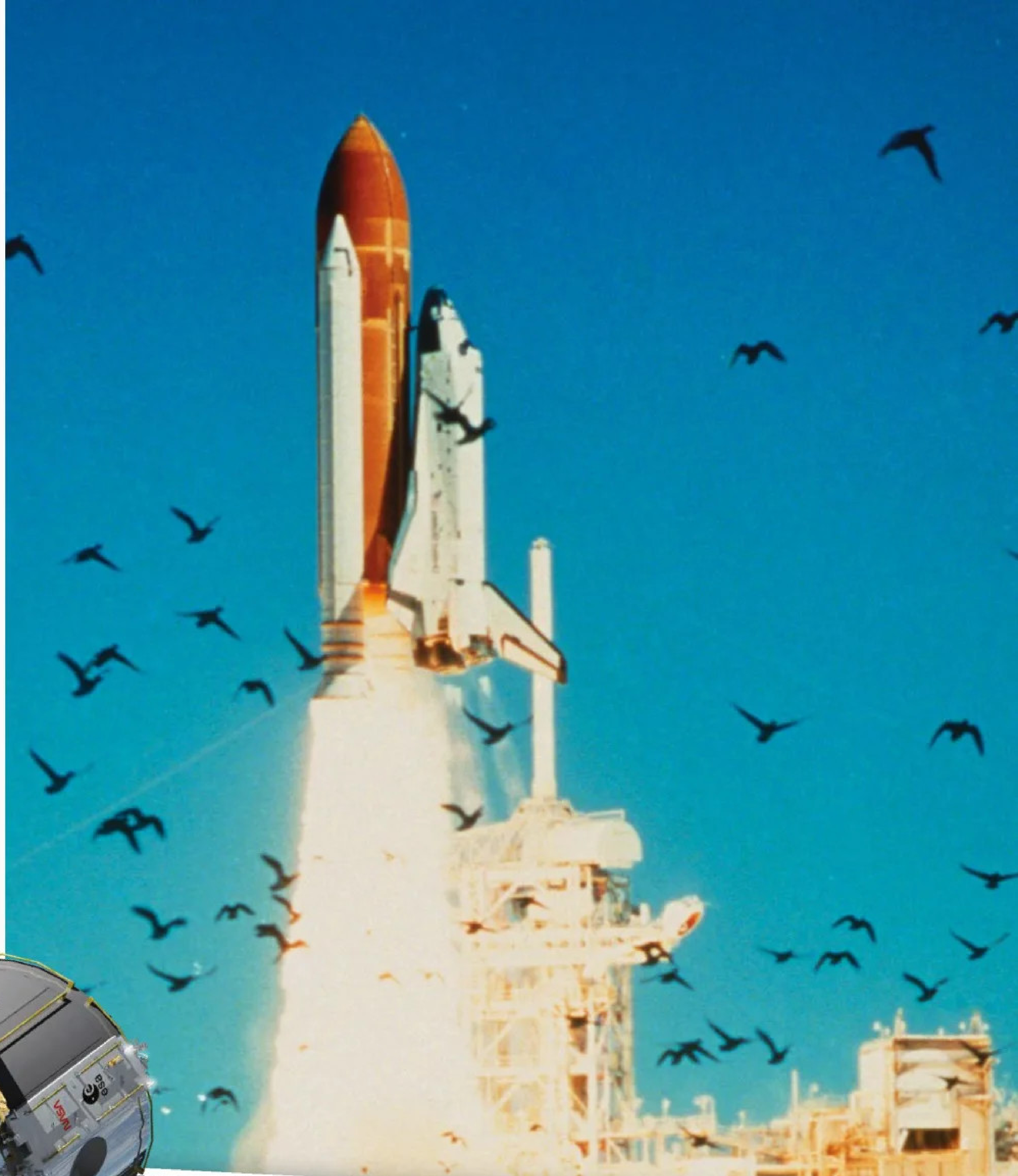
46 Apollo 10

48 Apollo 11

56 Apollo 13

58 Apollo 14

60 Apollo 15



## For all mankind

62 The story of Skylab

66 Apollo-Soyuz Test Project

68 The first Shuttle flight

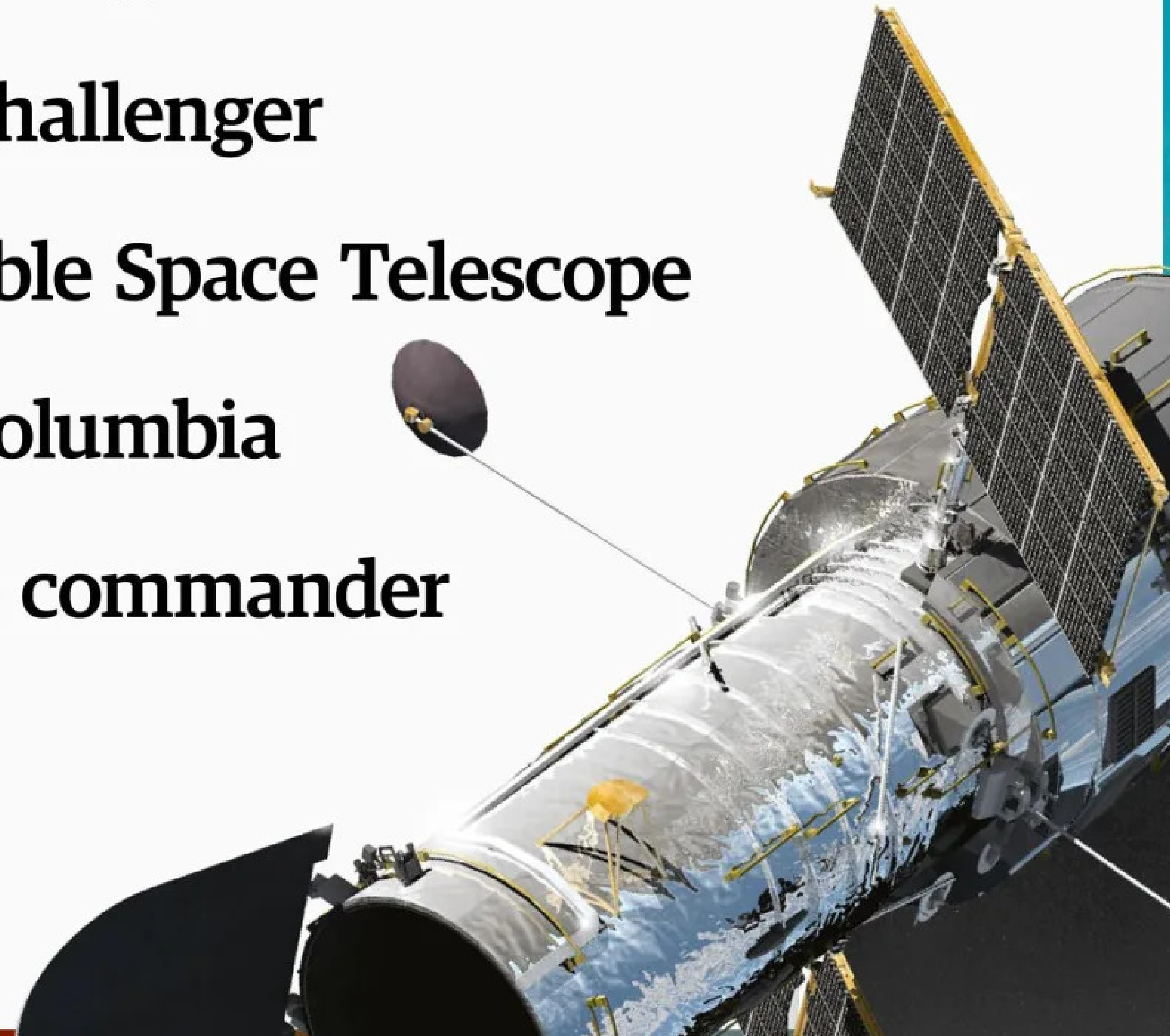
70 Space Shuttle Challenger

76 Saving the Hubble Space Telescope

79 Space Shuttle Columbia

84 The last Shuttle commander

88 A year in space



СОЮЗ
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## Unmanned missions

92 Beyond the Moon

94 Mission to Mars: Viking

96 Celebrating Voyager

104 What's next for Hubble?

110 Opportunity's 15 years on Mars

118 The curious case of Cassini-Huygens

120 New Horizons: Life after Pluto

## Innovations

124 What has NASA done for you?

# NASA takes flight

## Charged with developing the US civilian space programme, NASA was created with a sense of urgency in the late 1950s

Even before the final defeat of Nazi Germany in World War II, the Allied coalition that achieved victory had begun to fracture. The United States, Great Britain, and the Soviet Union had formed a military partnership in the face of Nazi aggression, but tenuous cooperation rapidly gave way to postwar rivalry.

Along with wartime advances in technology came the realisation that space exploration presented both peril and opportunity for the emergent super powers. East and West, motivated by nationalism and fear, sought to gain the upper hand. The nation that led in space might imperil the other's national security while threatening pre-emptive attack with nuclear weapons.

On 4 October 1957, this oneupmanship entered a new and dangerous dimension for the United States. The Soviet Union shocked the world with the launch of Sputnik I, the first manmade satellite to orbit the Earth. The Space Race was officially on, and the US was already lagging behind. Sputnik was the size of a basketball and weighed a mere 183 pounds, but it shook the American civilian and military establishments to the core. The little satellite's radio signals were heard by amateur operators, and a single low orbit of Earth was executed in 98 minutes. Those signals were perceptible for three weeks, and Sputnik orbited 1,440 times before its batteries finally died on 26 October 1957.

A month later Sputnik II followed, carrying a dog named Laika into space. Meanwhile, the United States continued its own attempt to get a satellite into orbit. In December 1957, Vanguard blew up moments after liftoff. On January 31, 1958, Explorer I became the first US satellite to orbit the Earth.

Still, Americans had discovered a new sense of vulnerability thanks to the Soviet initiative. Historian Geoffrey C Ward remembered, "…how frightening Sputnik seemed to me as a high-school kid, especially when I got a letter from an old friend in India that simply said, 'With this news, America is finished… What happened? How could America let this happen?' as if we had somehow lost control."

President Eisenhower presents Commissions of Office to Dr T Keith Glennan of Cleveland (right) and Dr Hugh L Dryden (left), NASA's first administrator and deputy administrator

The United States' first satellite, Explorer 1, being launched into orbit by a Juno 1 rocket

Central Intelligence Agency director Allen Dulles asserted that the Soviet launch had not surprised the US intelligence community, but the heightened fear factor was obvious. On 10 October 1957, less than a week after Sputnik spiralled spaceward, a meeting of the US National Security Council was called to assess its impact.

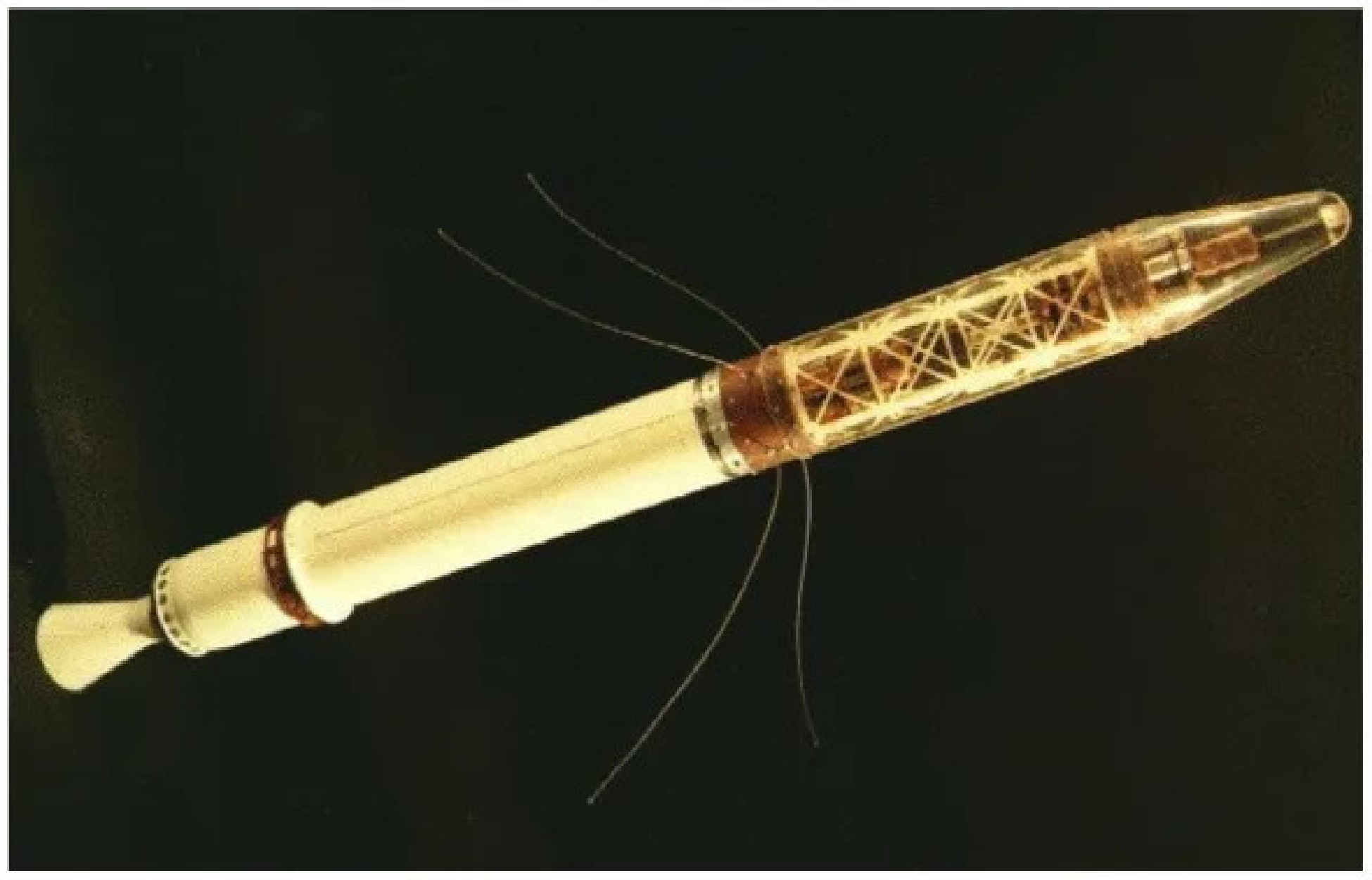
Subsequently, the Sputnik launches became the catalyst for the creation of an agency that would "…provide for research into the problems of flight within and outside Earth's atmosphere, and for other purposes." The US Congress passed legislation establishing NASA, the National Aeronautics and Space Administration, and President Eisenhower signed the act into law on 29 July 1958. By that autumn, NASA had absorbed the functions of its predecessor, the National Advisory Committee for Aeronautics (NACA) entirely.

The United States had long held an interest in the development of aviation, forming NACA in 1915. With aviation pioneers including Orville Wright involved, the charge for NACA was to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution."

Although the Wright Brothers, from Dayton, Ohio, had been the first to fly, NACA had been formed in response to the obvious successes of other nations, particularly as the military implications of aircraft were demonstrated during World War I. NACA conducted flight tests and evaluations of various aircraft models and established research facilities that used wind tunnels and innovative designs to maximise aircraft performance.

## America's entry: Explorer I

The first of more than 90 spacecraft in the Explorer series, Explorer I marked America's successful entry into the Space Race, launching on 31 January 1958 aboard a Juno rocket. It discovered the Van Allen radiation belt, and transmitted data to Earth for four months until its batteries expired. Explorer weighed 13.97 kilograms (30.8 pounds).



After World War II, NACA worked with the US Air Force and Bell Aircraft Company to develop the world's first supersonic aircraft, and on 14 October 1947, Chuck Yeager piloted the rocket-powered Bell X-1 aircraft in the first manned supersonic flight. NACA engineer Richard Whitcomb introduced the concept of area rule in 1951, leading to a design termed 'coke bottle' that diminished drag and increased an aircraft's ability to hit supersonic speed.

With the deepening of the Cold War, NACA began to focus on missile and space technology, including the delivery of nuclear warheads on distant targets, and then adding research into manned space vehicles. Such early endeavours paved the way for future aircraft designs that evolved into the spacecraft that carried American astronauts to the Moon and beyond.

In February 1955, the President's Scientific Advisory Committee issued the Killian Report, advocating that the best defensive posture in the nuclear age was one of deterrence, leading to

> "Sputnik was the size of a basketball and weighed a mere 183 pounds, but it shook the American civilian and military establishments to the core"

The Bell X-1 was a rocket-powered aircraft developed by NACA and built by Bell Aircraft. It was the first plane to exceed the speed of sound

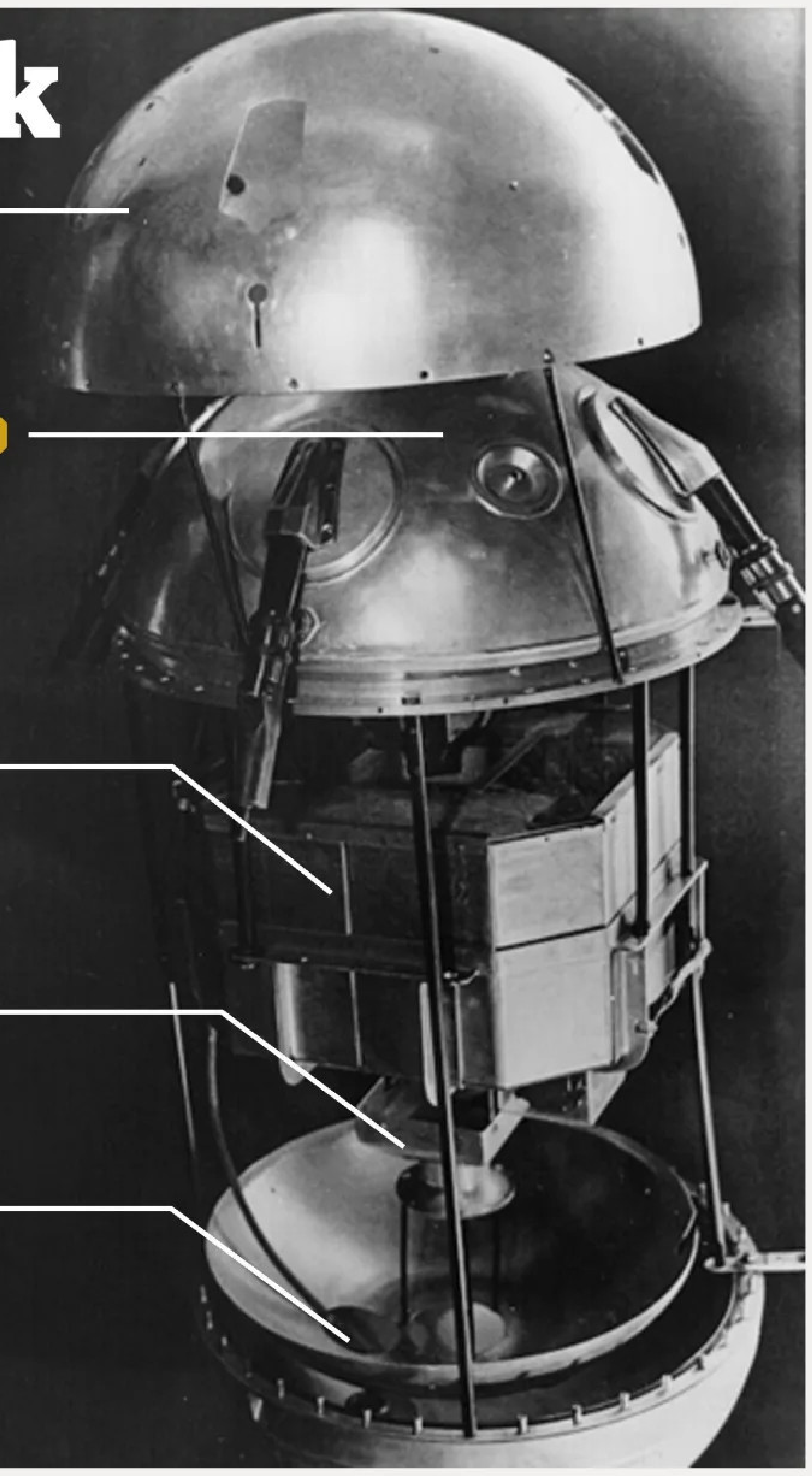
the doctrine of Mutually Assured Destruction in the event of nuclear war with the Soviet Union. In November 1957, NACA established its Special Committee on Space Technology, chaired by Dr H Guyford Stever of the Massachusetts Institute of Technology. It was concerned primarily with non-military and biomedical influences on the future of manned space flight and concluded that these facets of space research should be included in any federally supported space programme.

Both committees influenced the emergence of NASA in an atmosphere of urgency whipped up by the Soviet achievements of recent years. As NASA became operational in October 1958, its initial budget totalled $100 million, and it employed 8,000 people. Its facilities rapidly expanded from three major locations, Langley Aeronautical Laboratory in Virginia, Lewis Flight Propulsion Laboratory in Ohio, and Ames Aeronautical Laboratory in California, to ten sites across the United States.

Yet despite the angst about German and Russian technology that was prevalent among American leaders in the late 1950s, the father of modern rocket propulsion, and the inspiration for further research that led to the applications of such power in war and peace was, in fact, an American.

Dr Robert Goddard, a physicist, inventor, and professor of aerospace engineering at Clark University and later Princeton University, was experimenting with rocket propulsion in the early 20th century. As a boy, his father had showed him how to generate static electricity, and then as a teenager his reading of the science fiction novel *The War of the Worlds* by HG Wells had sparked an even greater interest in rocketry.As a student at Worcester Polytechnic Institute in Massachusetts, Goddard fired a gunpowder rocket in the basement of the physics building, generating a plume of smoke. Rather than expulsion, he earned the praise of the faculty. Seven years later, he secured two landmark US patents, one for a rocket propelled by liquid fuel and another for a solid fuel two- or three-stage rocket. Soon, though, his personal funds were running low, and in 1916 he petitioned the Smithsonian Institution for funding.

## Inside Sputnik



**External front hemisphere**
Sputnik I was designed as a sealed ball, and its top hemisphere was covered with a 1mm (0.0394in) thermal protective shield

**Pressurised internal shell**
The internal pressurised shell carried attachments for the antenna and the radio transmitter in a nitrogen atmosphere

**Radio and batteries**
Activated by a switch, the radio transmitter, developed by engineer VI Lappo, and batteries were topped with pressure and temperature sensors

**Internal cooling fan**
The cooling fan was installed to insist in maintaining an appropriate temperature and was activated by a thermal switch

**Lower internal and external hemispheres**
These hemispheres enclosed the operating equipment, and the outer surface was highly polished to reflect the light of the Sun

Dr Robert Goddard was a rocketry research pioneer

With $5,000 from the Smithsonian, Goddard pursued his work, reporting in 1920 on the possibilities of using rocket propulsion to send weather reporting equipment higher than balloons might reach. His paper was titled 'A Method of Reaching Extreme Altitudes'. Goddard also attracted media attention when, at the end of the paper, he alluded to the potential for a rocket to reach the moon. On 16 March 1926, he demonstrated the first successful flight of a liquid-fuelled rocket on his Aunt Effie's farm in Auburn, Massachusetts.

Still, the US government showed only passing interest in his work, and he depended on private funding to continue. Among his personal advocates was legendary pilot Charles Lindbergh, who persuaded the Guggenheim Foundation to provide funding. Along the way, he received another $5,000 from the Smithsonian. In 1929, one of his rockets carried a camera and a barometer into the sky, the world's first scientific payload. In 1936, he published a treatise on his efforts titled 'Liquid Propellant Rocket Development'.

Goddard's vision included power-driven fuel pumps, gyroscopic control and other innovations that were later components of the feared Nazi V-2 ballistic missile of World War II. During the war, he worked for the US Navy to successfully develop liquid-propelled rocket motors with variable thrust capabilities and jet takeoff assistance for aircraft. He died in 1945, having laid the foundation for the future exploration of space and providing the basis for the establishment of an entity such as NASA.

During World War II, the German rocketry programme advanced to the point of a tangible threat to Allied civilian and military targets. The research centre at Peenemünde on the Baltic Sea had become a target for Allied bombers, in the hope of suppressing the research that had led to the deployment of Adolf Hitler's 'Vengeance Weapons', the pulse-jet powered V-1 'Buzz Bomb' and the V-2 rocket, a ballistic missile capable of delivering a 1,000-kilogram (2,200-pound) warhead with devastating effect, particularly on the British cities that experienced it during the Blitz.

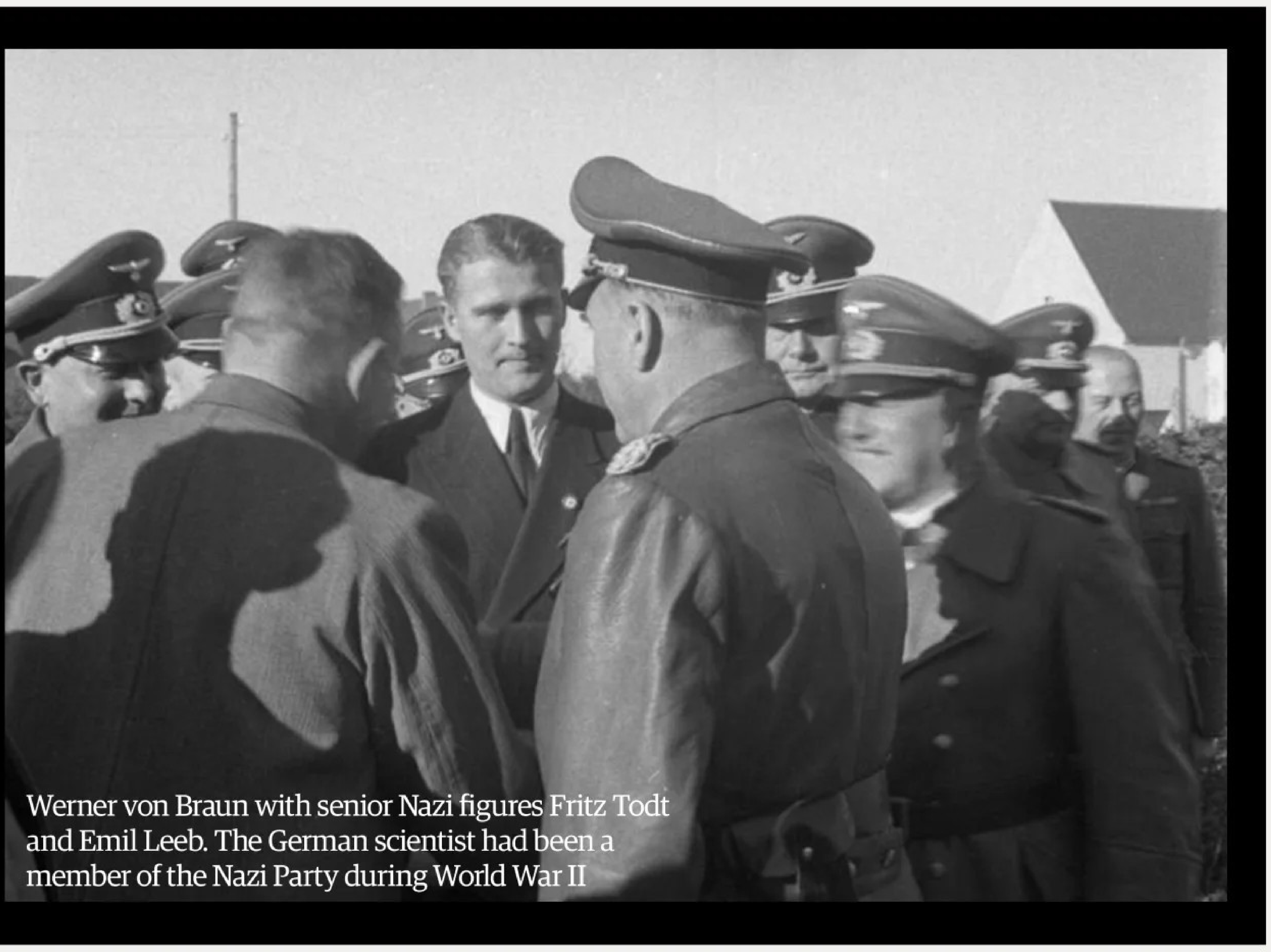
Although the development of the V-1 and V-2 came too late to affect the outcome of the war, the implications for the postwar world were clear. Rocket propulsion could be harnessed for military purposes, and existing defences against such threats were virtually non-existent.

As the war began to wane and Allied relations became strained, a competition developed between the US, Britain, and the Soviet Union to harvest the German technology that essentially was becoming the spoils of war, as well as to round up the brilliant scientists, engineers, and designers who had brought rocket propulsion and the ballistic missile from the theoretical to the practical sphere. The fact that

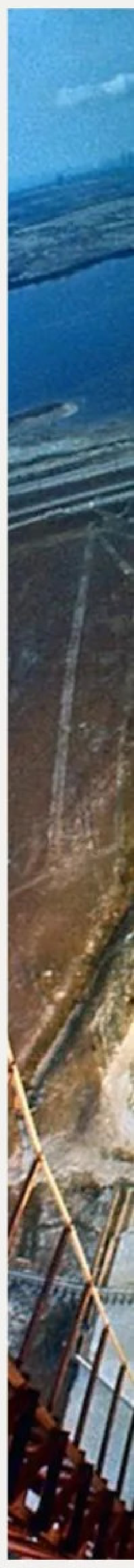
## The Nazi connection

Despite their primary focus as invaluable members of the American space programme's elite, the fact remains that the German scientists recruited to the United States had cooperated with the infamous regime of Nazi Germany during World War II, and probably knew of the atrocities committed at various work sites and concentration camps; stories of which emerged from time to time during their careers with NASA. The US government officially downplayed such odious activities during the early years of the space programme, however, as pressure mounted, inquiries were made concerning the involvement of some top-ranking German expatriates.

Wernher von Braun himself had been a member of the Nazi Party, applying in the autumn of 1937. He later explained that the affiliation was a requirement to carry on his research, involved no ideological indoctrination, and did not occur until 1939. Further clouding von Braun's reputation was the fact that he held the rank of major in the brutal SS, a highly indoctrinated Nazi paramilitary and military organisation that committed well-documented atrocities. Werner von Braun later said his SS membership had come under pressure from Reichsführer-SS Heinrich Himmler and was only ceremonial. Still, questions persist as to how much von Braun and his colleagues really knew about the war crimes committed at the Peenemünde research facility and elsewhere.



Werner von Braun with senior Nazi figures Fritz Todt and Emil Leeb. The German scientist had been a member of the Nazi Party during World War II



these individuals had served the Nazi regime and were – to a man – probably aware of the heinous use of slave labour to build these amazing machines, was necessarily shunted aside in anticipation of a new world order and the requisite military capabilities that would either bring on another devastating war or a tenuous peace.

While Britain staged Operation Backfire, launching at least three captured V-2s by October 1945, and extracting as much information as possible from the German scientists who had surrendered to them, the United States enacted Operation Lusty to retrieve and transport across the Atlantic Ocean as much German hardware as possible, especially relating to jet and rocket-powered aircraft designs. Operation Paperclip, meanwhile, was a far-reaching American effort to recruit and enlist the aid of German scientists who had developed the technology for the V-2 and other key weapons.

Operation Paperclip continued in one form or another from the end of the war through to 1959. Paperclip was eventually successful in bringing more than 1,600 German scientists to the United States in the wake of World War II, while the Soviet Union's Operation Osaviakhim brought at least 2,200 to their country, many at gunpoint and with family members as hostages if they were uncooperative.

The most influential group of German scientists to reach the United States was the rocket team led by Wernher von Braun, who had developed the V-2. The brilliant von Braun had become interested in astronomy and space exploration as a boy, after his mother had given him a telescope as a gift. He idolised the racers who set speed records in the 1920s while driving rocket-propelled cars.

Interestingly, von Braun did not excel in his studies as a teen. However, his perspective changed after reading the book *By Rocket into Planetary Space* by German pioneer Hermann Oberth. After refocusing his efforts, von Braun participated in early liquid-fuelled rocket engine testing, earning a doctorate in physics at Friedrich-Wilhelm University in Berlin in

> "Operation Paperclip was a far-reaching American effort to enlist the aid of German scientists who had developed the technology for the V-2 rocket"

NACA
NACA
USAF
USAF

The NACA Test Force at the High-Speed Flight Station in Edwards, California during 1952. The plane at the front is a rocket-and jet-powered Douglas Skyrocket, capable of supersonic speeds

Apollo 11 – the vehicle carrying the first manned Moon landing – blasts off on a Saturn V rocket from Kennedy Space Center Launch Complex 39A on 16 July 1969

1934, just months after the Nazi Party gained power in Germany.

By that time, von Braun was already working with the German Army under the tutelage of Captain Walter Dornberger, an artillery officer, who secured a grant for von Braun to continue research for a thesis labelled 'About Combustion Tests', a portion of his full body of work. The complete thesis, 'Construction, Theoretical, and Experimental Solution to the Problem of the Liquid Propellant Rocket', was classified. Research was restricted to the military.

Werner von Braun worked at the army's solid fuel rocket testing site in Kummersdorf, and later confirmed that his efforts were heavily influenced by Goddard's earlier findings. As technical director at Peenemünde, von Braun supervised the development of liquid fuelled rocket engines that assisted aircraft takeoffs, the supersonic Wasserfall anti-aircraft missile, and the A-4 ballistic missile, forerunner of the V-2. After less than two years of research and development, the first V-2 was launched against the UK on 7 September 1944.

As the end of the war approached, von Braun ordered many of the group's top-secret plans to be hidden in a mineshaft in the Harz Mountains. He gathered his associates and asked them to consider to whom they would surrender. The majority chose to look to the West. From Bavaria, where the scientists were under SS guard, they made their way to Austria. On 2 May 1945, von Braun's brother Magnus chanced upon soldiers of the US 44th Infantry Division and explained, "My name is Magnus von Braun. My brother invented the V-2. We want to surrender."

Werner von Braun poses in his office at NASA Headquarters in Washington, DC, in 1970. His role at the time was deputy associate administrator for planning

For more than 30 years, von Braun and other top German scientists, including physiologist Hubertus Strughold, the 'Father of Space Medicine', Walter Dornberger – instrumental in the development of the X-15 aircraft, nuclear capable missile designs, and whose work contributed to the creation of the Space Shuttle – and Werner Dahm, chief aerodynamicist at the Marshall Space Flight Center in Huntsville, Alabama, worked with the US Army and then with NASA. Early work surrounded the testing of rockets at White Sands Proving Ground in New Mexico. In 1950, the rocket team relocated to Redstone Arsenal in Huntsville, and in 1960 the Army programme was placed under the auspices of NASA. Although he had worked for the military in both Germany and the US, von Braun had always hoped to lead a project that would place man on the Moon.

On 25 May 1961, President John F Kennedy declared before Congress that the nation "should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth". With the continuing pressure of the Soviet space programme and Kennedy's words ringing in his ears, von Braun led tremendous progress in the US. space programme. Among other achievements, he became director at the Marshall Space Flight Center and chief designer of the Saturn rocket, leading to the Saturn V booster that did indeed propel astronauts to the surface of the Moon in 1969. Von Braun died in 1977, after retiring from NASA and working for Fairchild Industries in Maryland, Virginia.

NASA, however, has continued its pioneering space programmes, with subsequent lunar missions, Skylab, the Apollo-Soyuz mission, the Space Shuttle, the cooperative International Space Station, further exploration of the universe, and a potential manned mission to Mars.

# America's secret space race

## Many early American space projects were shrouded in military secrecy as the US military raced to compete with their rivals in the Soviet Union

Throughout the Space Race of the 1950s and 1960s, military competition was often an unspoken subtext – and sometimes one that bubbled to the surface. While Cold War rivals the USA and Soviet Union could guard their land and sea borders, the air was a different matter, with altitude providing an obvious advantage. Fly high enough in the atmosphere, or reach space itself, and there was little your competitors could do to protect themselves from prying eyes – or worse. As a result, the various branches of the US military and secret intelligence services took a keen interest in the development of high-altitude aircraft and satellites – with consequences that would ultimately influence NASA's space programme.

Despite its ostensibly civilian credentials, the National Advisory Council on Aeronautics (NACA, NASA's immediate precursor) was often involved in these projects. From the 1940s onwards, it guided development of a series of 'X-planes' that pushed the boundaries of flight. The first of these, the Bell X-1, became globally famous in 1947 as the plane flown through the sound barrier by US Air Force (USAF) test pilot Chuck Yeager.

Other X-planes, however, were less well known – and often developed under a veil of secrecy to test new flight concepts or for specific military applications. For example, the X-16, also built by Bell, was in fact a cover for the development of a squadron of high-altitude reconnaissance planes, ordered by the US Air Force in 1954 and cancelled two years later.

NACA and NASA were frequently drawn into this sort of murky area – most infamously when they were used as a civilian 'front' for the CIA and US Air Force U-2 spy plane. Unable to completely hide the U-2 from public scrutiny, the US government instead explained it as a high-altitude NACA craft for weather research. U-2s began to overfly the Soviet Union and allied countries from 1956, and supplied crucial intelligence in the early days of the Space Race, including the first photographs of the Baikonur Cosmodrome in Kazakhstan a few months before the launch of Sputnik 1. However, the plane's scientific cover story was embarrassingly undermined in 1960 when missiles brought one down over Russia and its pilot, Gary Powers, was captured and questioned.

Although the U-2 and similar aircraft would continue to be used to overfly other countries and in situations that required fast access to imagery (such as the 1962 Cuban Missile Crisis), it was clear even in the mid-1950s that spy satellites could offer a better long-term surveillance solution. Located above the atmosphere, they were safe from hostile aircraft or ground-based missiles, and though they might be tracked, there was little an overflown territory could do about it.

The US Air Force began to develop plans for a spy satellite under the codename 'Corona' in 1956. Two years later, the project was transferred to the secretive Advanced Research Projects Agency (ARPA). At the time, it was impossible to capture electronic images and return them from orbit with sufficiently high resolution, so the satellites relied instead on a mechanical solution known as 'Keyhole'. Images were captured on a reel of photographic film using a specially designed camera. At the end of the mission, the film reels were ejected from the satellite in a heat-shielded conical recovery capsule. A parachute deployed in the lower atmosphere, and ideally the capsule could be captured in mid-air by a specially equipped recovery aircraft.

The first Corona satellite, named Discoverer 1, was ready to fly in January 1959. Its true purpose hidden behind a cover story of scientific research, it was to be launched from California's Vandenberg Air Force Base on a Thor-Agena launch vehicle. This was a modification of the USAF's Thor ballistic missile programme, whose development lagged behind the Army Redstone rockets at the core of NASA's first scientific satellite launches.

However, a launchpad explosion of the upper stage destroyed the satellite while it was still on the ground, and this was just the start of a long string of failures, as either the troublesome launch vehicle, or the satellite itself, malfunctioned. It was not until August 1960 that Discoverer 13 finally returned a capsule successfully from orbit – the first recovery of a man-made object from space in history.

As Corona began to return useful intelligence, the rate of launches rapidly accelerated and secrecy grew, with the programme folded into a newly established National Reconnaissance Office. From 1962 the Discoverer name was dropped, and from 1963 the entire project was classified Top Secret and disappeared from view behind a variety of codenames. We now know that it continued until 1972 before being replaced by the more advanced KH-9 Hexagon satellite series known as 'Big Bird'.

Meanwhile, other X-planes were also pushing the boundaries, and raising questions about how America might put a man in space before the Soviet Union. The X-15 design, in particular, was to play a key role in

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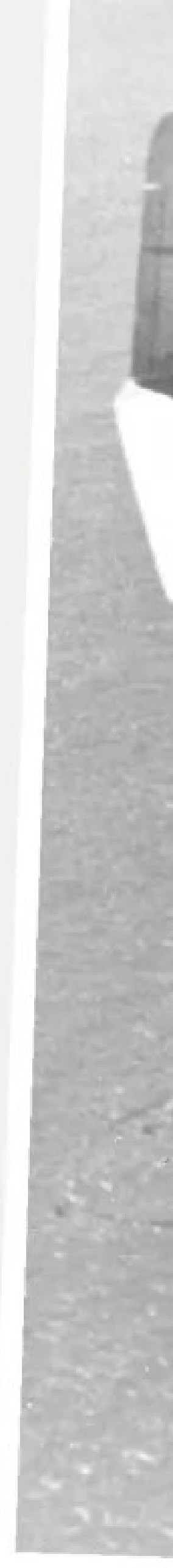


early space exploration. Launched from a B-52 carrier plane at an altitude of around 13.7 km (8.5 miles), this rocket-powered aircraft had a longer fuselage and used new alloys to resist the heat generated from friction with the surrounding air at hypersonic speeds (greater than Mach 5, or five times the speed of sound). The new aircraft had the potential to reach the edge of space (considered by the USAF to be an altitude of 80 km or 50 miles), and was fitted with an innovative 'reaction control system' – a series of small rocket thrusters (similar to those used on later manned spacecraft) that could alter its orientation in conditions where conventional aerodynamics failed. Even before it had flown, some were questioning just how far the X-15 might be pushed.

In the aftermath of the Sputnik crisis, the USAF's Air Research and Development Command (ARDC) convened a secret conference with military contractors in January 1958 to outline a future space programme. Overtaken not only by the Soviets but also disconcerted by the successful launch of the

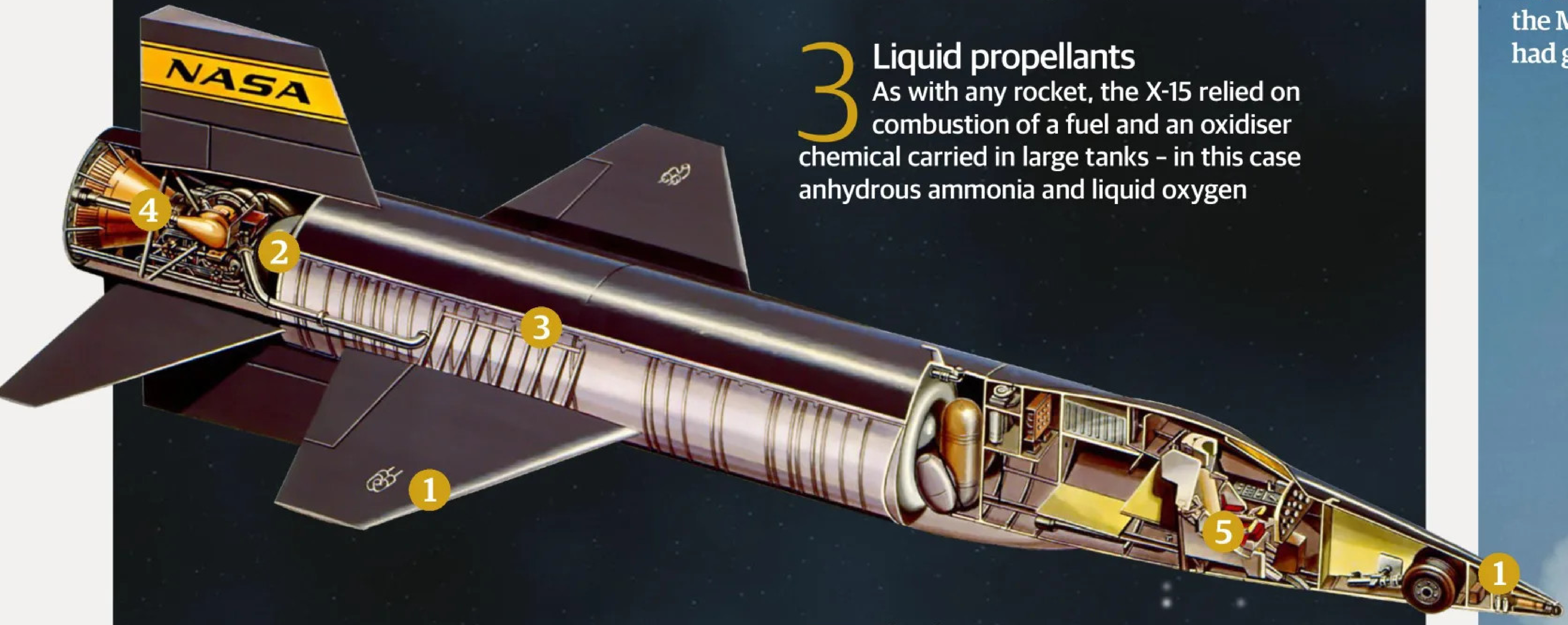
## The nearly man

Neil Armstrong missed out on becoming a USAF astronaut not just once, but three times. As well as his brief involvement in the MISS project, he became an X-15 test pilot, but did not take part in any of the aircraft's flights into space. And he was chosen as a candidate astronaut for the X-20 Dyna-Soar programme – but as that ill-fated project ran into funding difficulties of its own, he elected to apply for NASA's own astronaut selection programme in 1962.

**1 Reaction control system**
Small thruster rockets on the wingtips and nose allowed the X-15 to adjust its orientation in effectively airless conditions

**2 Turbopump**
A high-speed pump powered by combustion of hydrogen peroxide could supply 6,800kg (15,000lb) of fuel and propellant to the main rocket engine in just 80 seconds

**3 Liquid propellants**
As with any rocket, the X-15 relied on combustion of a fuel and an oxidiser chemical carried in large tanks – in this case anhydrous ammonia and liquid oxygen

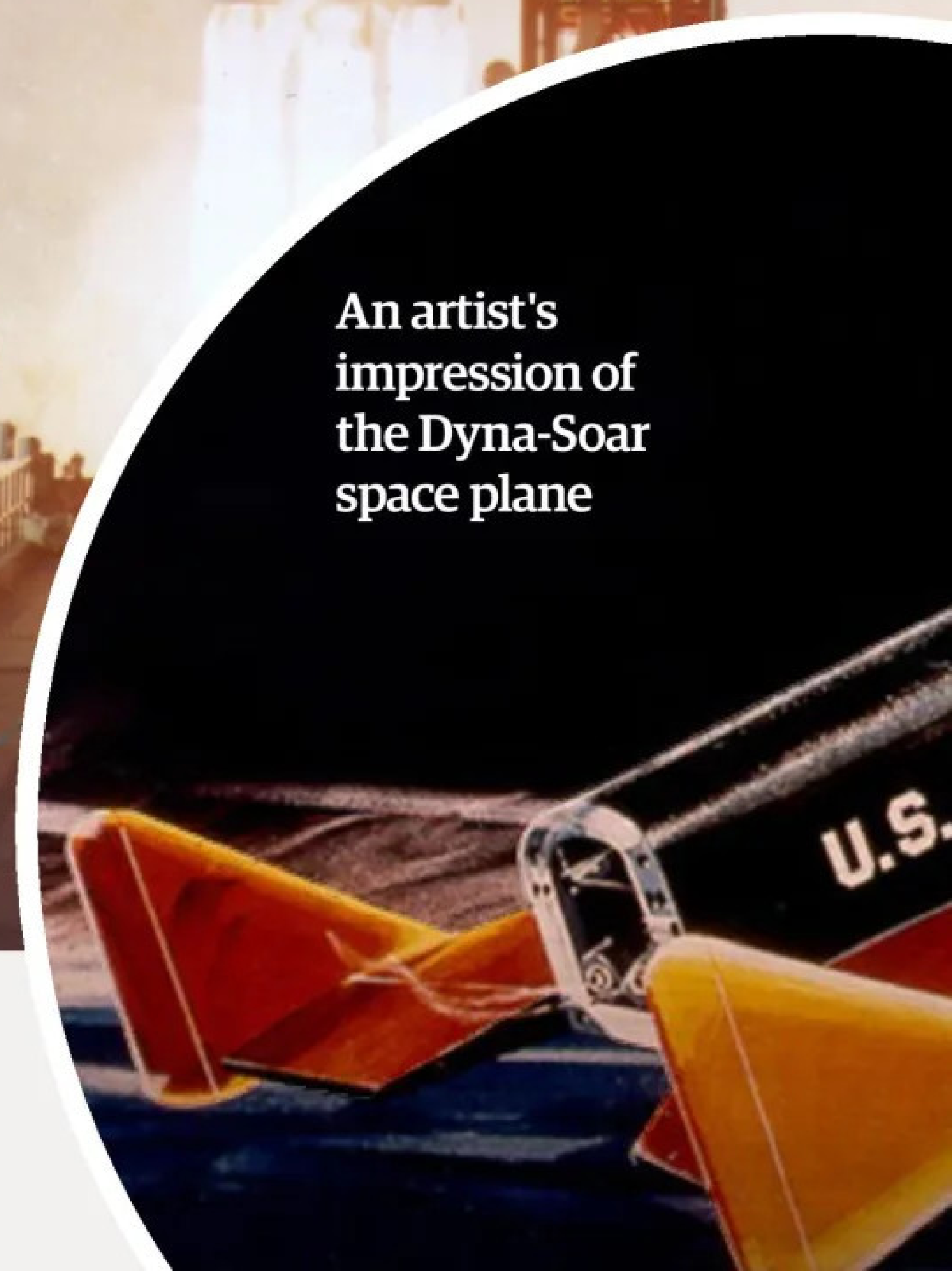


**4 Rocket engine**
The XLR-99 engine fitted to the X-15 in 1960 could generate 250 kilonewtons of thrust – roughly equivalent to the total thrust created by the twin engines of the famous F-15 Eagle jet fighter

**5 The hot seat**
The X-15 pilot wore an astronaut-like pressure suit. At high altitudes, nitrogen gas was used to pressurise the cabin, with oxygen supplied to the pilot through a separate system. An ejector seat could theoretically function at speeds of up to Mach 4

A U-2 spy plane bearing fictitious NASA markings. This was supposed to disguise the programme as weather research

An Atlas-Agena rocket launching Lunar Orbiter 4 on 4 May 1967. It's likely that this type of rocket would have been used on the MISS programme if it had gone ahead

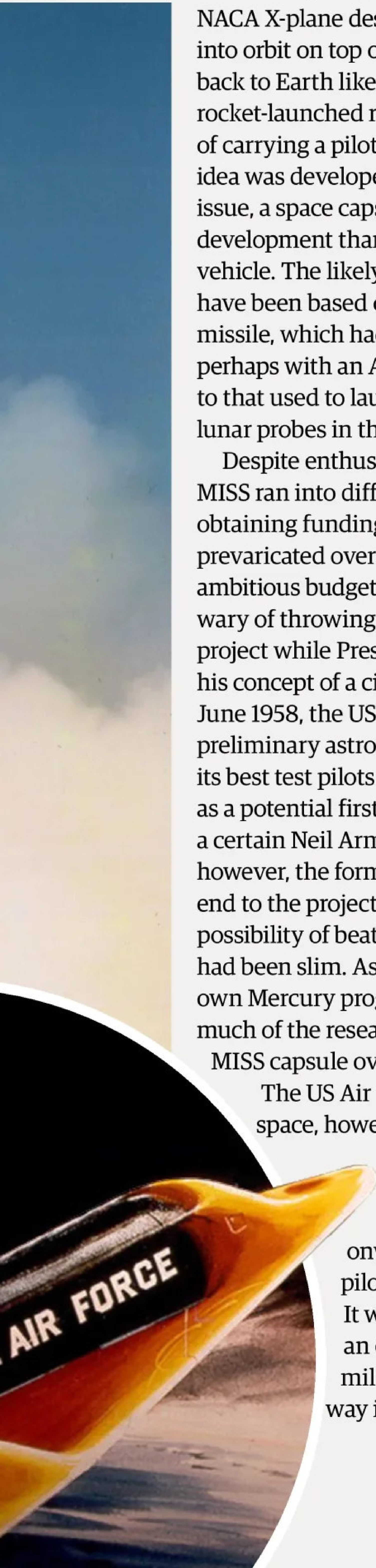


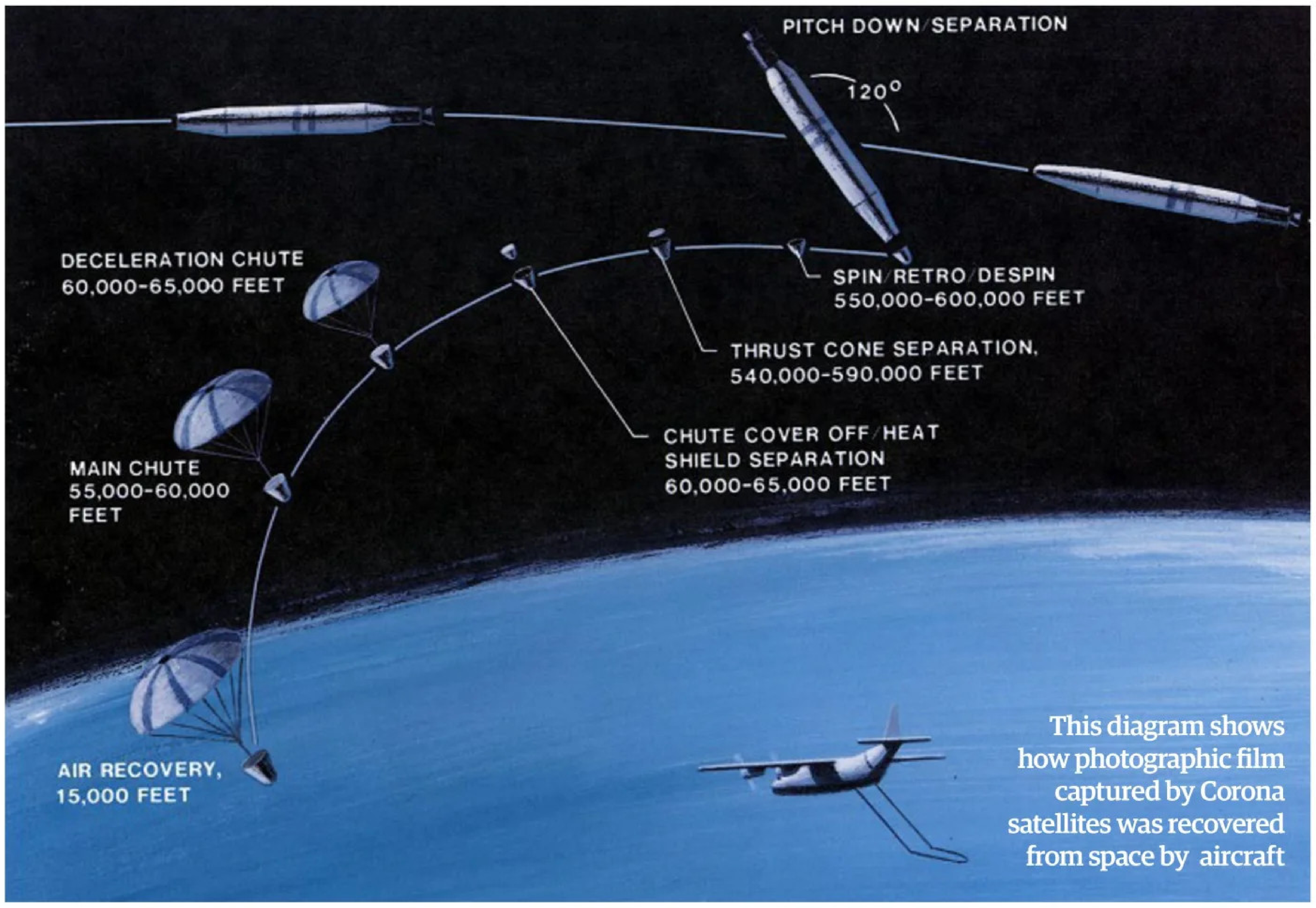
An artist's impression of the Dyna-Soar space plane

Explorer 1 satellite using Wernher von Braun's US Army rockets, they focused on three 'Man-In-Space-Soonest' (MISS) options that could put the US (and specifically the USAF) back at the head of the Space Race. One was to develop the X-15B, a modification of the as-yet-unflown X-15 that could hypothetically reach altitudes of 120 km and the speed of Mach 21 necessary for a stable orbit. Another was to accelerate the X-20 'Dyna-Soar' project – another USAF/NACA X-plane designed to launch vertically into orbit on top of a rocket and glide back to Earth like a plane. The third was a rocket-launched re-entry capsule capable of carrying a pilot. In the end, only the last idea was developed – with speed a crucial issue, a space capsule would require far less development than an aerodynamic flying vehicle. The likely launch vehicle would have been based on the USAF's Atlas ballistic missile, which had just entered service, perhaps with an Agena upper stage similar to that used to launch NASA unmanned lunar probes in the 1960s.

Despite enthusiasm at the USAF, however, MISS ran into difficulties when it came to obtaining funding. Agencies such as ARPA prevaricated over their contribution to an ambitious budget, and politicians were wary of throwing their backing behind the project while President Eisenhower pushed his concept of a civilian space agency. In June 1958, the USAF optimistically made a preliminary astronaut selection from among its best test pilots. The names considered as a potential first man in space included a certain Neil Armstrong. A month later, however, the formation of NASA had put an end to the project, and, with hindsight, the possibility of beating Yuri Gagarin into orbit had been slim. As NASA geared up for its own Mercury programme, it benefited from much of the research that had gone into the MISS capsule over those few short months.

The US Air Force did eventually reach space, however. Following an engine upgrade, the X-15 made 13 flights beyond the edge of space from July 1962 onwards, earning eight test pilots their astronaut wings. It was a fitting postscript to an era where it seemed the military might lead America's way into space.





This diagram shows how photographic film captured by Corona satellites was recovered from space by aircraft

> "The names considered as a potential first man in space included a certain Neil Armstrong"

© NASA, USAF, US National Reconnaissance Office

# RISE *OF THE* SPACE AGE

Shadowed by the fear of war, the initial launch of Sputnik revealed humanity at its boldest

Written by Ben Evans

Over 60 years ago, the world gazed at the sky and listened through shortwave radio receivers with fascination and fear. For millennia, humans had clung to the Earth's surface, only recently having mastered the long-held dream of flight and with scant awareness of what lay beyond the thin veil of the atmosphere. But, on 4 October 1957, our sense of place in the cosmos changed forever. Over three weeks, a steady 'beep-beep' transmission from Sputnik 1 – the first artificial satellite – heralded the dawn of the Space Age. Yet the euphoria of conquering space was met by harsh Cold War reality, as Russia and America sought to deliver weapons of enormous destruction across intercontinental distances.

For something that changed the world, Sputnik 1 was an unremarkable icon. It was a polished metal sphere, 23-inches across, with four antennae to broadcast radio pulses at 20.005 MHz and 40.002 MHz, easily audible to amateur radio listeners. Circling the globe at 65-degrees of inclination, its flight path carried it over virtually the entire inhabited Earth, completing an orbit every 96.2 minutes. Its signal vanished when its batteries died, and the 184-pound satellite burned up in the atmosphere in January 1958.

Thus began the Space Race between the capitalist United States and the communist Soviet Union to attain mastery over the heavens. Following the World War II, both nations used captured German scientists and rockets (including the infamous V-2) to further their ambitions of building intercontinental ballistic missiles to establish technological and ideological supremacy over the other. Juxtaposed against this bellicose stance was the 1957-1958 International Geophysical Year, a concerted 18-month campaign of Earth science research. In the summer of 1955, the United States and the Soviet Union pledged to launch a satellite during the IGY.

Politically, Sputnik 1 was a great shock, and demolished Western perceptions of Russia as a backward nation of potato farmers. Science-fiction writer Arthur C. Clarke reflected that on 4 October 1957, the United States became a second-rate world power, while economist Bernard Baruch praised the Soviet "imagination to hitch its wagon to the stars" and stressed that American paranoia was well founded. During his 1960 presidential campaign, John F. Kennedy played into this palpable sense of national dread by claiming that Soviet hegemony in space could someday afford them control of the Earth.

After the 'Sputnik Crisis', political figures increasingly spoke of a 'gap' in missile-building technology, with the United States falling behind the Soviet Union. Indeed, the Soviets created the world's first intercontinental ballistic missile – the R-7 – and test flew it across a distance of 3,700 miles, before using a modified version to launch Sputnik 1. Remarkably, the same basic rocket is still used to launch satellites and humans today. The missile gap was promulgated by the Gaither Report in November 1957, which recommended a significant strengthening of US military might. Its figures were exaggerated, but the fiction of a missile gap galvanised America into forming NASA in October 1958, and accelerated the development of rockets to send men into space.

America's ascendancy in space began with disappointment. In December 1957, a Vanguard rocket exploded on the launch pad, triggering a media frenzy. Journalists mocked it as 'Kaputnik', while Soviet delegates to the United Nations tauntingly wondered if the United States needed aid as an "undeveloped nation". Finally, on 31 January 1958, Explorer 1 became America's first successful satellite. Six weeks later, it was followed by Vanguard 1, disparagingly nicknamed "the grapefruit" by Soviet Premier Nikita Khrushchev. However, the smallness of these early satellites belied their advanced scientific capabilities. Explorer 1 discovered the Earth's Van Allen radiation belts, while Vanguard 1 remains the oldest man-made object still in orbit today.

The benefits of satellites for a range of applications – from communications to reconnaissance and navigation to scientific research – had long been recognised, and in December 1958, the first test of a relay was used to broadcast Christmas greetings from US President Dwight D. Eisenhower. Two years later, Echo 1 became the world's first passive communications satellite, followed by Telstar, which transmitted television pictures, telephone calls and telegraph images, as well as a live transatlantic feed between the United States and Belgium.

It was Arthur C. Clarke who first widely disseminated the idea of putting satellites into 'geostationary' orbit, more than 22,000 miles above the Earth, matching the planet's rotation for worldwide communications. Syncom 3 was the

To date, 12 people have left their footprints on the Moon

© NASA; Getty/Bjorn Holland

# The great Space Race

## From tiny satellites to boots on the Moon, humanity took great strides in a single decade

UNITED STATES | 1955 | SOVIET UNION

**4 October 1957** Sputnik 1, world's first artificial satellite.

**3 November 1957** Sputnik 2, carried first living creature into orbit.

**31 January 1958** Explorer 1, America's first satellite.

**12 September 1959** Luna 2, first mission to crash-land on the Moon.

1960

**4 October 1959** Luna 3, first images of the far side of the Moon.

**5 May 1961** Alan Shepard, America's first man in space.

**12 April 1961** Yuri Gagarin, first man in space.

**20 February 1962** John Glenn, America's first man to orbit the Earth.

**16 June 1963** Valentina Tereshkova, first woman in space.

**3 June 1965** Ed White, America's first spacewalk.

**15 December 1965** Gemini 7 and 6, first rendezvous in space.

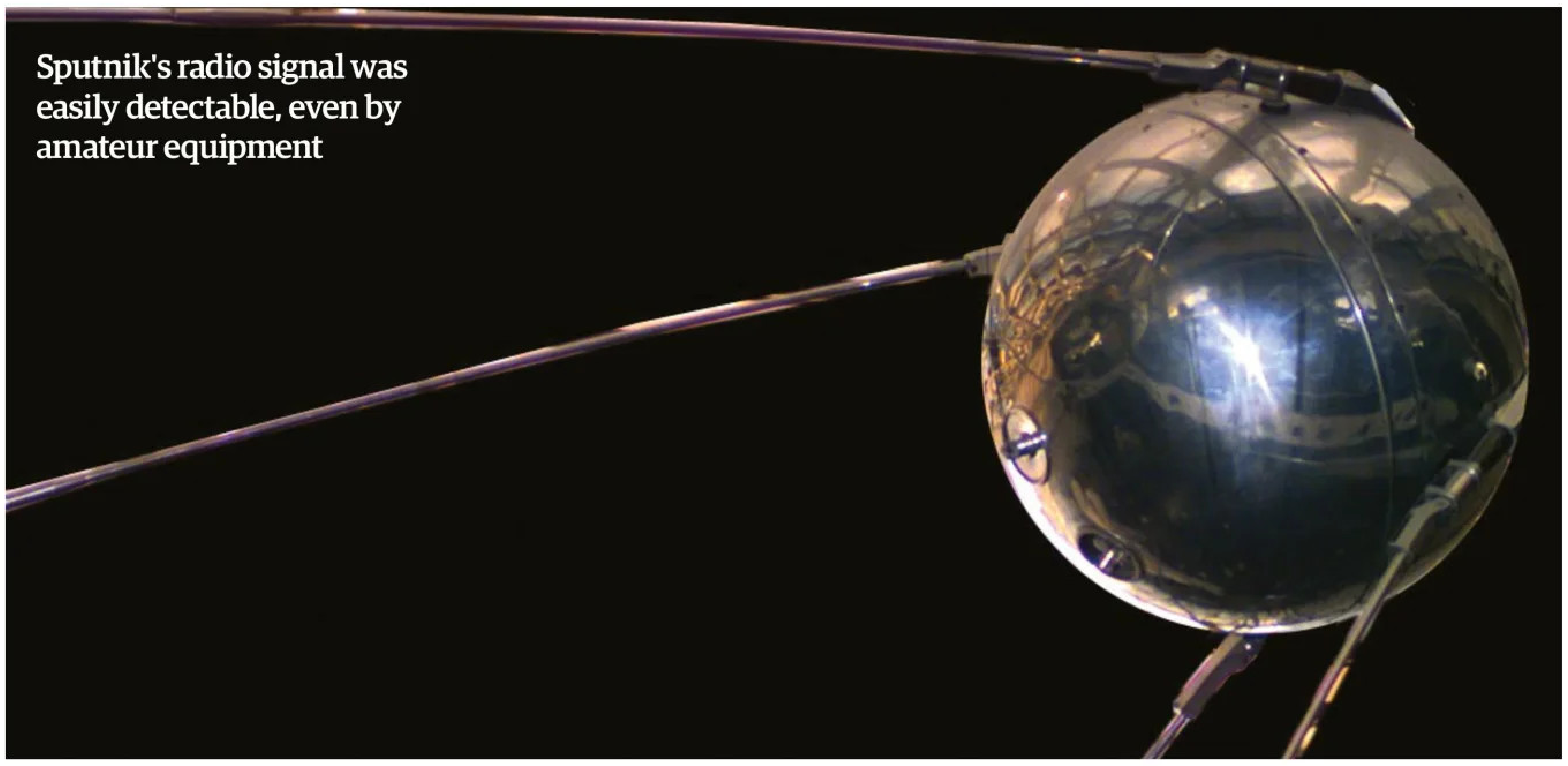
**18 March 1965** Alexey Leonov, first spacewalk.

**16 March 1966** Gemini 8, first docking in space.

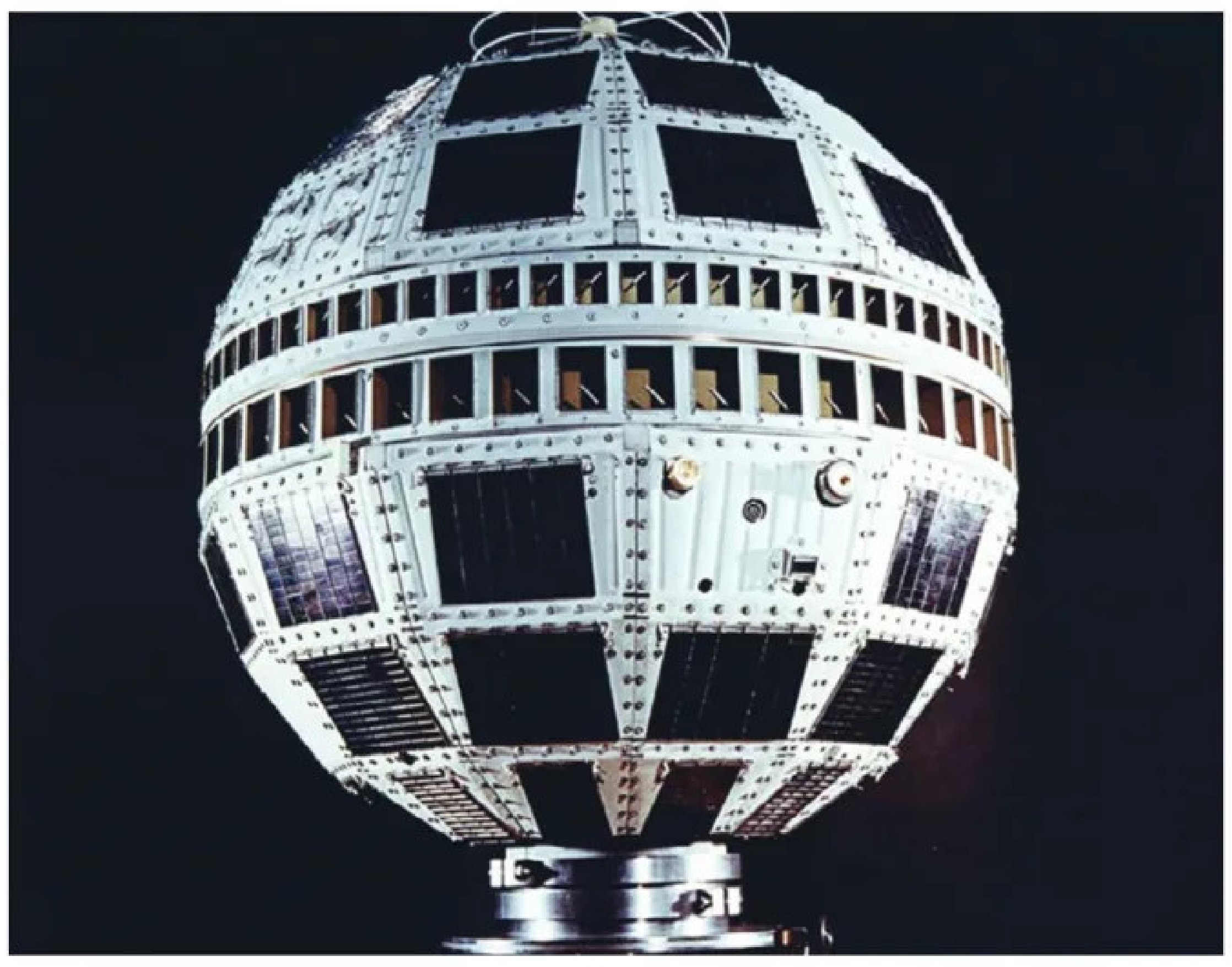
**24 December 1968** Apollo 8, first mission to orbit the Moon.

**21 July 1969** Apollo 11, first piloted landing on the Moon.

1970



Sputnik's radio signal was easily detectable, even by amateur equipment



The US eventually overtook the USSR and won the Space Race

first to reach this high orbit, relaying images from the 1964 Summer Olympics in Tokyo. This laid the foundation for hundreds more communications satellites, which continue to deliver telephone, television, radio and internet services.

Of course, the Cold War inspired less peaceful activities, too, and planning for reconnaissance satellites was set in motion early in the Space Age. However, it was only after the infamous shootdown of Gary Powers' U-2 reconnaissance aircraft in May 1960 that the need for military eyes in space became commonplace. In August of that year, Discoverer 13 became the first satellite to return an object safely to Earth, in the form of a classified film canister. Less than two weeks later, the Soviets brought their Korabl-Sputnik 2 spacecraft, carrying the dogs Belka and Strelka, back home. It was the first time that living creatures had been launched into orbit and returned alive.

Sending living creatures, and eventually humans, into space was an important driving force. In November 1957, the Soviets launched Sputnik 2, carrying a dog, Laika. Several animals had already flown above the 62-mile-high 'Kármán line' – the internationally recognised boundary for the edge of space – but three-year-old Laika was first to actually achieve orbit. Following a stressful launch, Laika died within hours when the cabin overheated. Her legacy is that she unmasked some of the unknowns about the survivability of launch, orbital acceleration and the effects of weightlessness. Laika laid the groundwork for the 108-minute orbital flight of Yuri Gagarin, the first man in space, on 12 April 1961.

> "The pendulum shifted in the mid-1960s, and truly America took the lead"

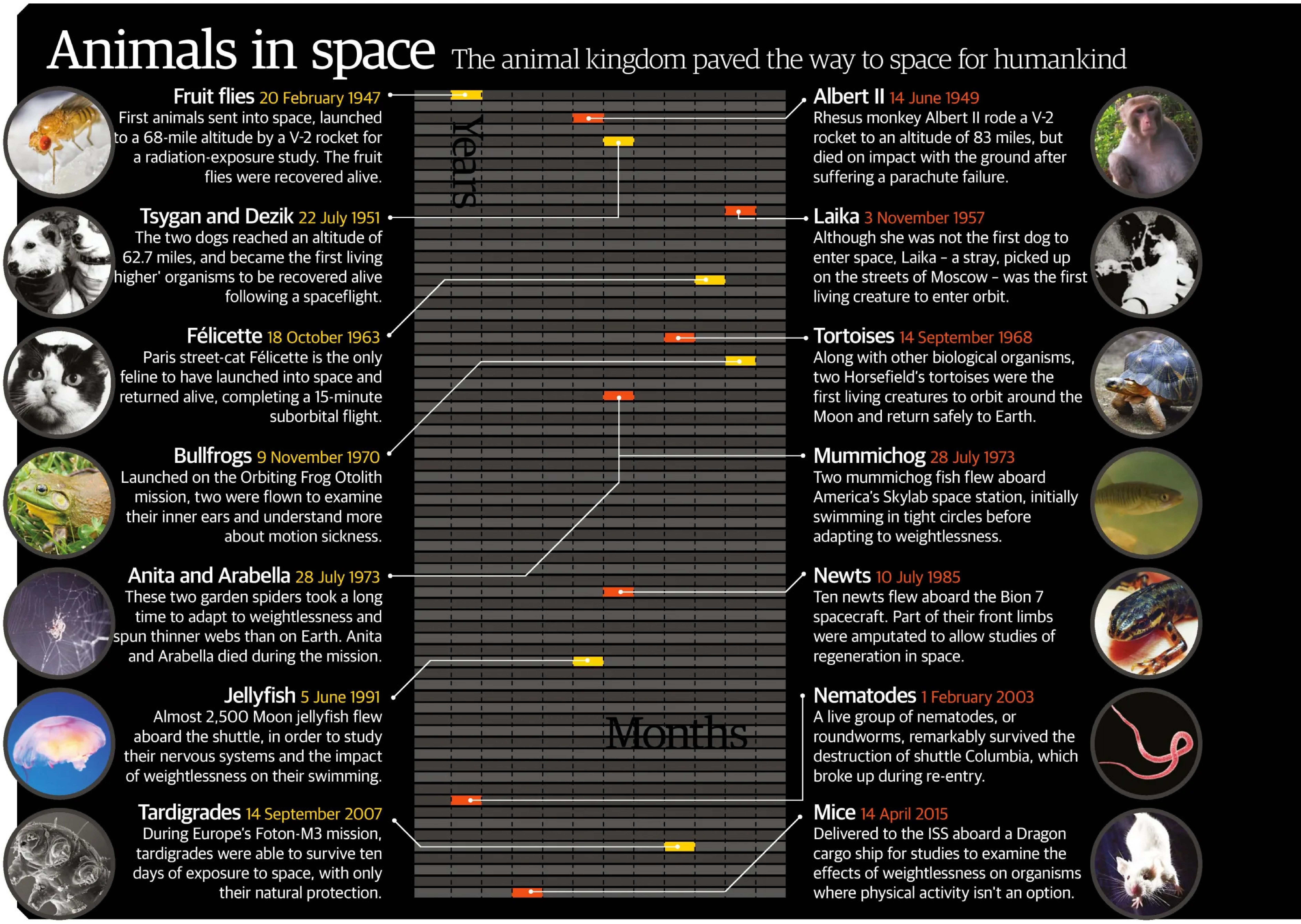
If Sputnik 1 shocked the world, then Gagarin's mission shocked it again, particularly as it occurred only months into the administration of President John F Kennedy. Matters worsened when CIA attempts to overthrow Fidel Castro failed, leaving Kennedy humiliated, and in need of a means to re-establish his nation's prestige. Although Alan Shepard became America's first man in space on 5 May 1961, his Redstone booster was only capable of a 15-minute suborbital flight. Not until the following year did John Glenn – riding the larger, more powerful Atlas rocket – actually achieve orbit.

Despite such limited spaceflight experience, Kennedy told a joint session of Congress that he intended to direct the United States to land a man on the Moon before the end of the decade. It was a challenging gamble, since lunar exploration had been pioneered by the Soviets. In January 1959, Luna 1 became the first man-made object to reach the Moon, measuring the solar wind, and eventually entering heliocentric orbit. Before the year ended, Luna 2 had been intentionally crashed into the surface, and Luna 3 returned the first photographs of the Moon's far side, never before seen by human

© NASA; NASA/JPL; U.S. Navy; ESA/Dr. Ralph O. Schill; Science Photo Library / Alamy Stock Photo; Francisco Romero Ferrero; Dinesh 317; Aaron Logan; Carl D. Howe; Brian gratwicke; Christian Fischer; Husky

## Animals in space

The animal kingdom paved the way to space for humankind



**Fruit flies** 20 February 1947
First animals sent into space, launched to a 68-mile altitude by a V-2 rocket for a radiation-exposure study. The fruit flies were recovered alive.

**Albert II** 14 June 1949
Rhesus monkey Albert II rode a V-2 rocket to an altitude of 83 miles, but died on impact with the ground after suffering a parachute failure.

**Tsygan and Dezik** 22 July 1951
The two dogs reached an altitude of 62.7 miles, and became the first living higher' organisms to be recovered alive following a spaceflight.

**Laika** 3 November 1957
Although she was not the first dog to enter space, Laika – a stray, picked up on the streets of Moscow – was the first living creature to enter orbit.

**Félicette** 18 October 1963
Paris street-cat Félicette is the only feline to have launched into space and returned alive, completing a 15-minute suborbital flight.

**Tortoises** 14 September 1968
Along with other biological organisms, two Horsefield's tortoises were the first living creatures to orbit around the Moon and return safely to Earth.

**Bullfrogs** 9 November 1970
Launched on the Orbiting Frog Otolith mission, two were flown to examine their inner ears and understand more about motion sickness.

**Mummichog** 28 July 1973
Two mummichog fish flew aboard America's Skylab space station, initially swimming in tight circles before adapting to weightlessness.

**Anita and Arabella** 28 July 1973
These two garden spiders took a long time to adapt to weightlessness and spun thinner webs than on Earth. Anita and Arabella died during the mission.

**Newts** 10 July 1985
Ten newts flew aboard the Bion 7 spacecraft. Part of their front limbs were amputated to allow studies of regeneration in space.

**Jellyfish** 5 June 1991
Almost 2,500 Moon jellyfish flew aboard the shuttle, in order to study their nervous systems and the impact of weightlessness on their swimming.

**Nematodes** 1 February 2003
A live group of nematodes, or roundworms, remarkably survived the destruction of shuttle Columbia, which broke up during re-entry.

**Tardigrades** 14 September 2007
During Europe's Foton-M3 mission, tardigrades were able to survive ten days of exposure to space, with only their natural protection.

**Mice** 14 April 2015
Delivered to the ISS aboard a Dragon cargo ship for studies to examine the effects of weightlessness on organisms where physical activity isn't an option.

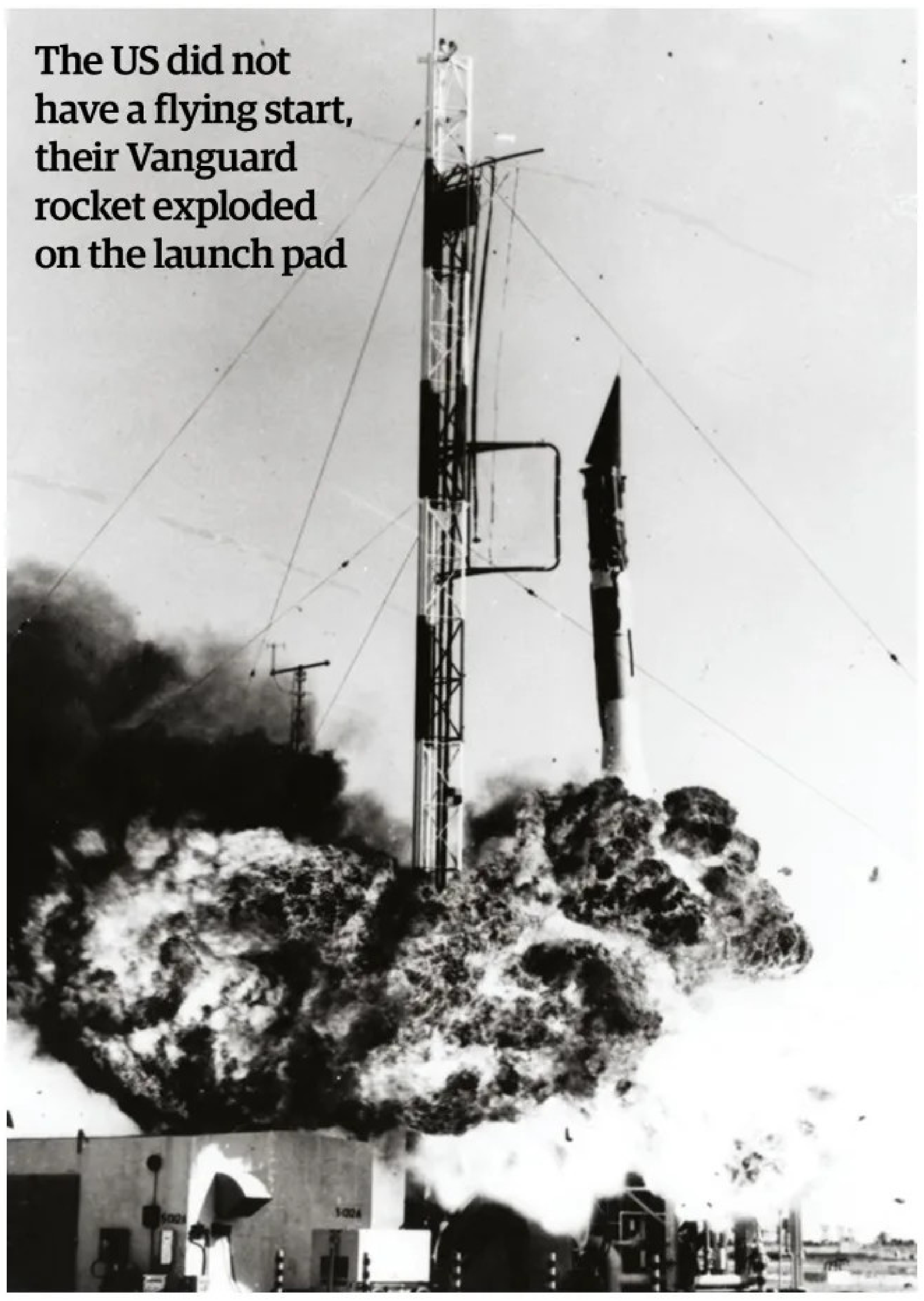
eyes. On 3 February 1966, a Soviet spacecraft, Luna 9, performed the first soft landing on another celestial body.

Russia also held the advantage in human space exploration, flying cosmonauts into orbit for several days, sending the first woman into space, launching the first multi-person spacecraft and executing the world's first spacewalk. However, the pendulum shifted in the mid-1960s, and America took the lead, flying longer missions, performing spacewalks and docking with other spacecraft. Its investment in Kennedy's goal peaked at 5 per cent of the federal budget. Meanwhile, the Soviets suffered the premature death of their chief rocket designer, Sergei Korolev, and the advantage slipped from their fingers. Yet the dangers of space exploration were ever-present. America lost three Apollo astronauts in a launch pad fire in January 1967 and, just three months later, a Russian cosmonaut plunged to his death when the parachutes on his descending Soyuz spacecraft failed to open.

In spite of the emphasis on reaching the Moon, both nations also turned their attention further afield, with the United States completing the first flyby of Mars with Mariner 4 in July 1965. The spacecraft's photographs revealed a hostile world, with no evidence of wind or water erosion, and a virtual absence of a magnetic field. Soviet missions to the Red Planet were more troubled: three exploded during launch, and another was lost during its outward journey. Mariner 2 flew past Venus in December 1962, while Russia's Venera 3 was first to crash-land on the planet's surface in March 1966. A year later, Venera 4 became the first spacecraft to take direct measurements from another planet's atmosphere, revealing carbon dioxide as Venus' main constituent.

The race to the Moon continued unabated. In November 1967, America test flew its Saturn V lunar rocket for the first time, and the following September, Russia launched the Zond 5 spacecraft around the Moon, carrying a payload which included mealworms, wine flies, plants and a pair of tortoises. They became the first living creatures to venture into deep space, visit our closest celestial neighbour and return safely to Earth.

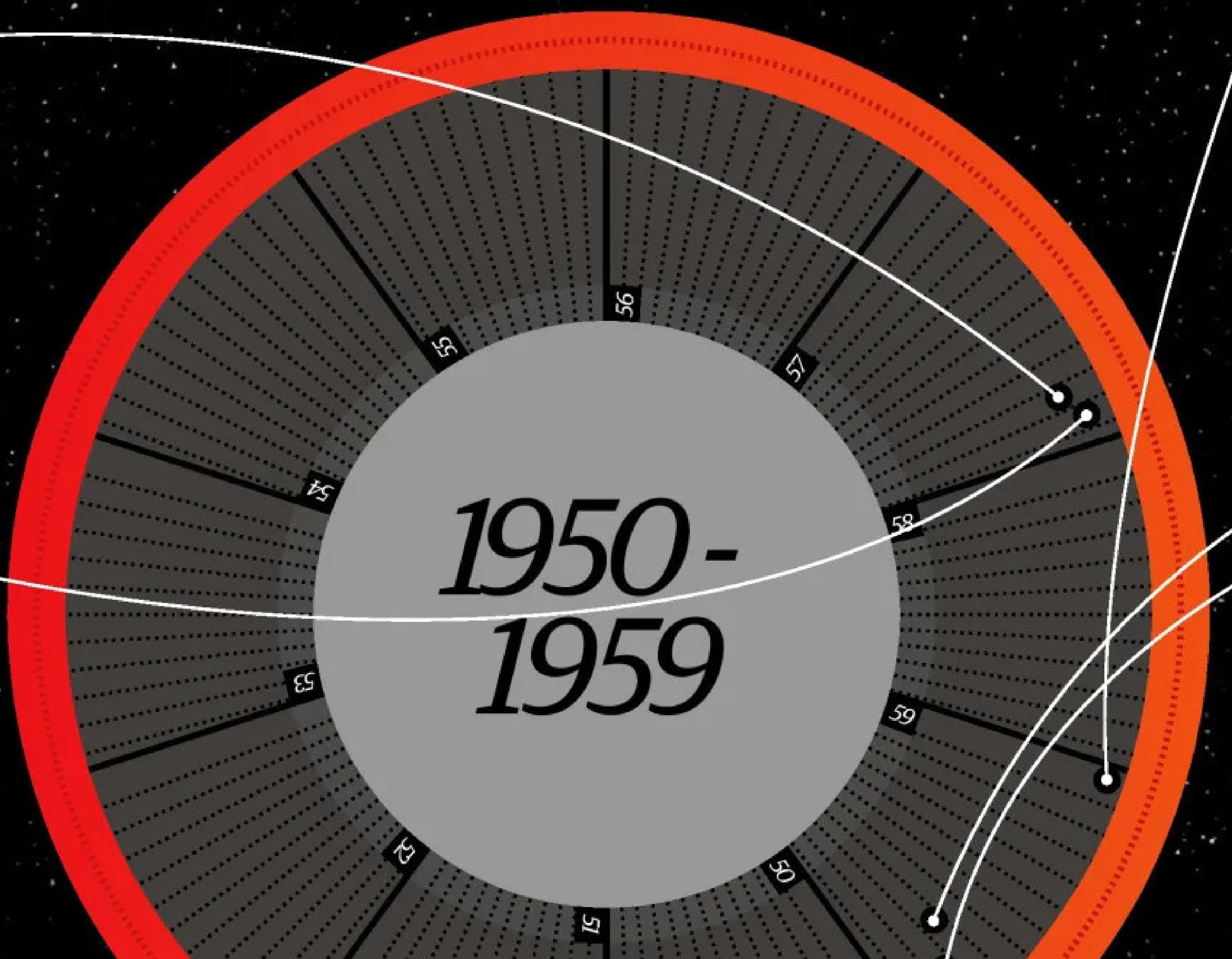
As the end of the decade approached and the final lap of the space race began, CIA intelligence



**The US did not have a flying start, their Vanguard rocket exploded on the launch pad**

# Space Age timeline

The US and Russia pressured each other into great advances



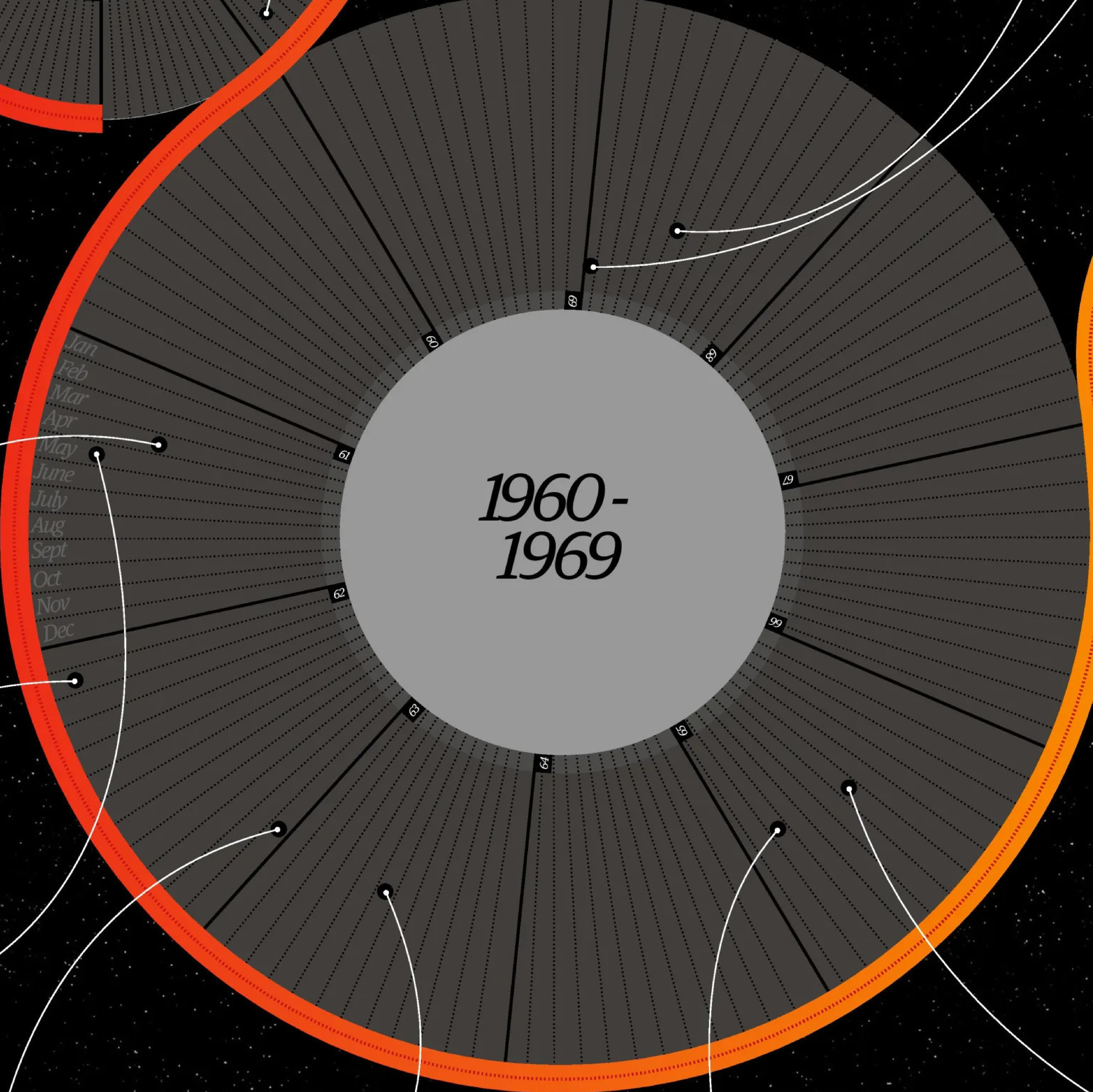
**4 October 1957**
Sputnik 1, the world's first artificial satellite, spent three months in space and travelled 43 million miles and 1,440 orbits of the Earth

**3 November 1957**
Launch of the dog Laika, the first living creature to enter orbit around the Earth. She died within hours, when the cabin of her Sputnik 2 satellite overheated

**2 January 1959**
Launch of Luna 1, the first spacecraft to depart Earth's gravitational field and reach the distance of the Moon. It is now in heliocentric orbit

**12 September 1959**
Luna 2 became the first spacecraft to physically impact the Moon, crash-landing in the Mare Imbrium region, close to the craters Aristides, Archimedes and Autolycus

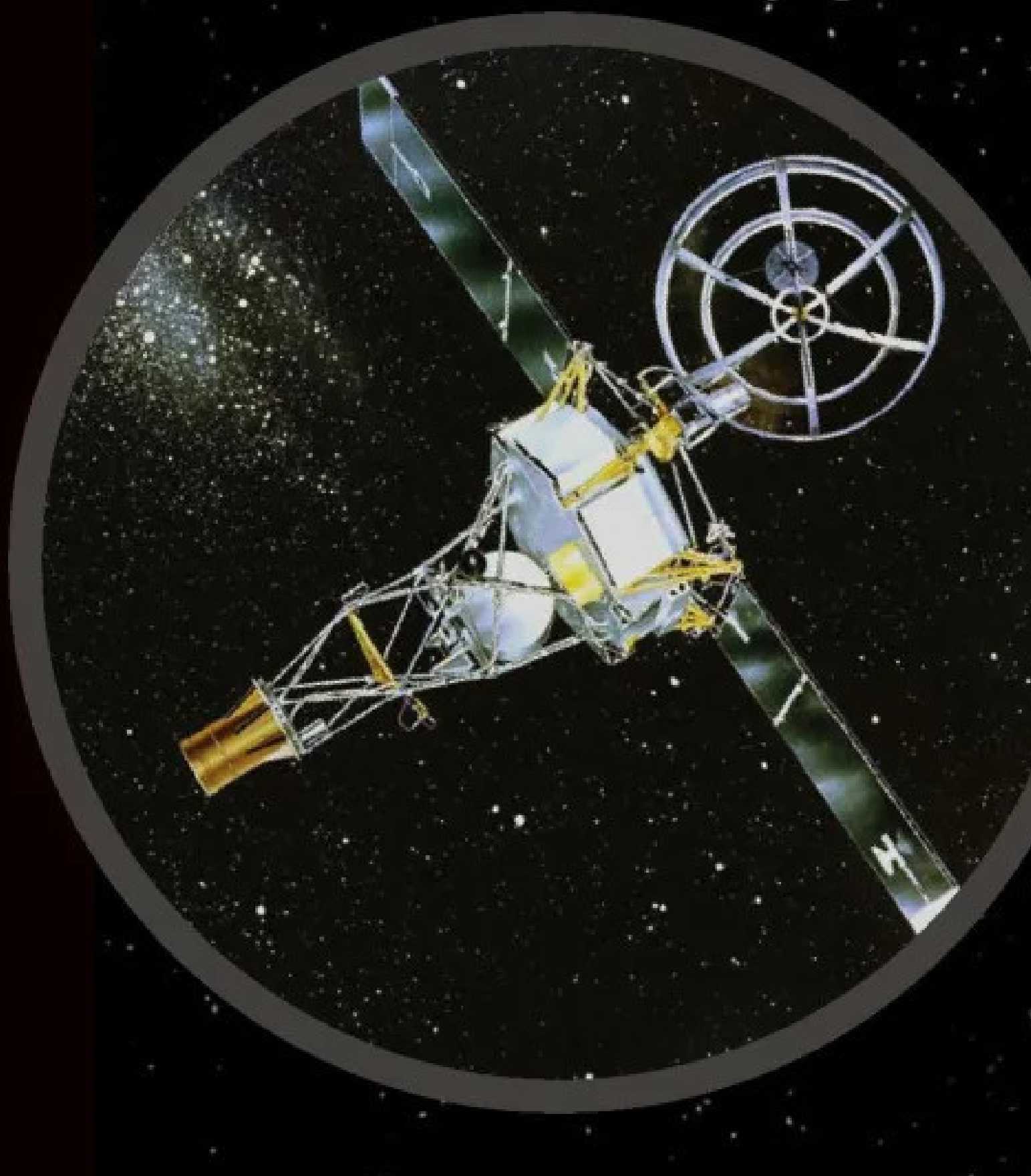
**7 October 1959**
Never before seen by human eyes, the lunar far side, as seen for the first time by Luna 3, proved to be mountainous, with very few low-lying plains



**12 April 1961**
Atop a modified version of Sergei Korolev's R-7 intercontinental ballistic missile, Yuri Gagarin became the first human being to enter space and complete a single Earth orbit

**20 February 1962**
John Glenn became the first American to orbit the Earth, launching aboard a modified Atlas intercontinental ballistic missile and returning to a splashdown in the Atlantic Ocean

**5 May 1961**
Three weeks after Gagarin's triumph, Alan Shepard became America's first man in space. He flew a 15-minute suborbital voyage aboard the Freedom 7 capsule



**14 December 1962**
Mariner 2 became the first spacecraft to successfully encounter another planet when it flew within 18,700 miles of Venus, revealing thick atmospheric clouds

**16 June 1963**
Former factory worker Valentina Tereshkova was hurriedly trained as part of a propaganda campaign by the Soviet Union to secure a record for the first woman in space

**18 March 1965**
For 16 minutes, Alexey Leonov floated in the vacuum of space, protected only by his pressurised suit. In doing so, he became the world's first spacewalker

© NASA; Adrian Mann; Chinese Space Agency

**20 July 1969**
After millennia of gazing upward at the Moon, the space race officially ended when Neil Armstrong and Buzz Aldrin triumphantly set foot on the Sea of Tranquillity

hinted a large Soviet rocket, the N-1, was undergoing final preparations to send a pair of cosmonauts around the Moon. Reconnaissance satellite imagery showed the rocket on its launch pad and, in August 1968, America hurriedly moved to upgrade Apollo 8 from an Earth-orbital flight to a lunar voyage. In just four months, the mission rose from the drawing-board to reality, and astronauts Frank Borman, Jim Lovell and Bill Anders became the first men from Earth to settle into orbit around the Moon.

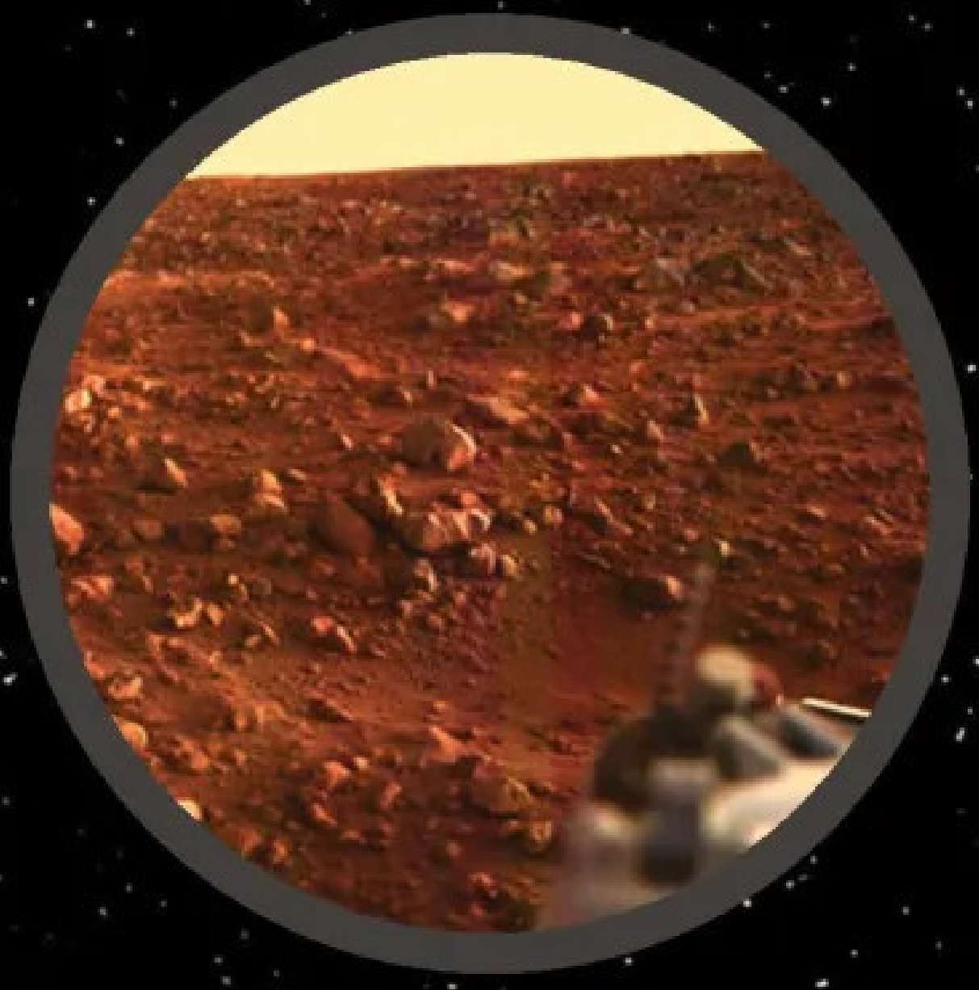
The N-1, meanwhile, suffered two catastrophic failures in February and July 1969, eliminating the last remaining Soviet hope of somehow getting cosmonauts onto the lunar surface before Neil Armstrong and Buzz Aldrin. Another unmanned spacecraft, Luna 15, sought to tame the impending American triumph by bringing some lunar soil back to Earth, but it ignominiously crashed into the Moon a few hours after Armstrong and Aldrin landed at the Sea of Tranquility.

With the space race won, political attitudes changed. The Soviets refocused their attention on building long-term space stations in Earth orbit, while America developed the shuttle as a more cost-effective means of reaching space.

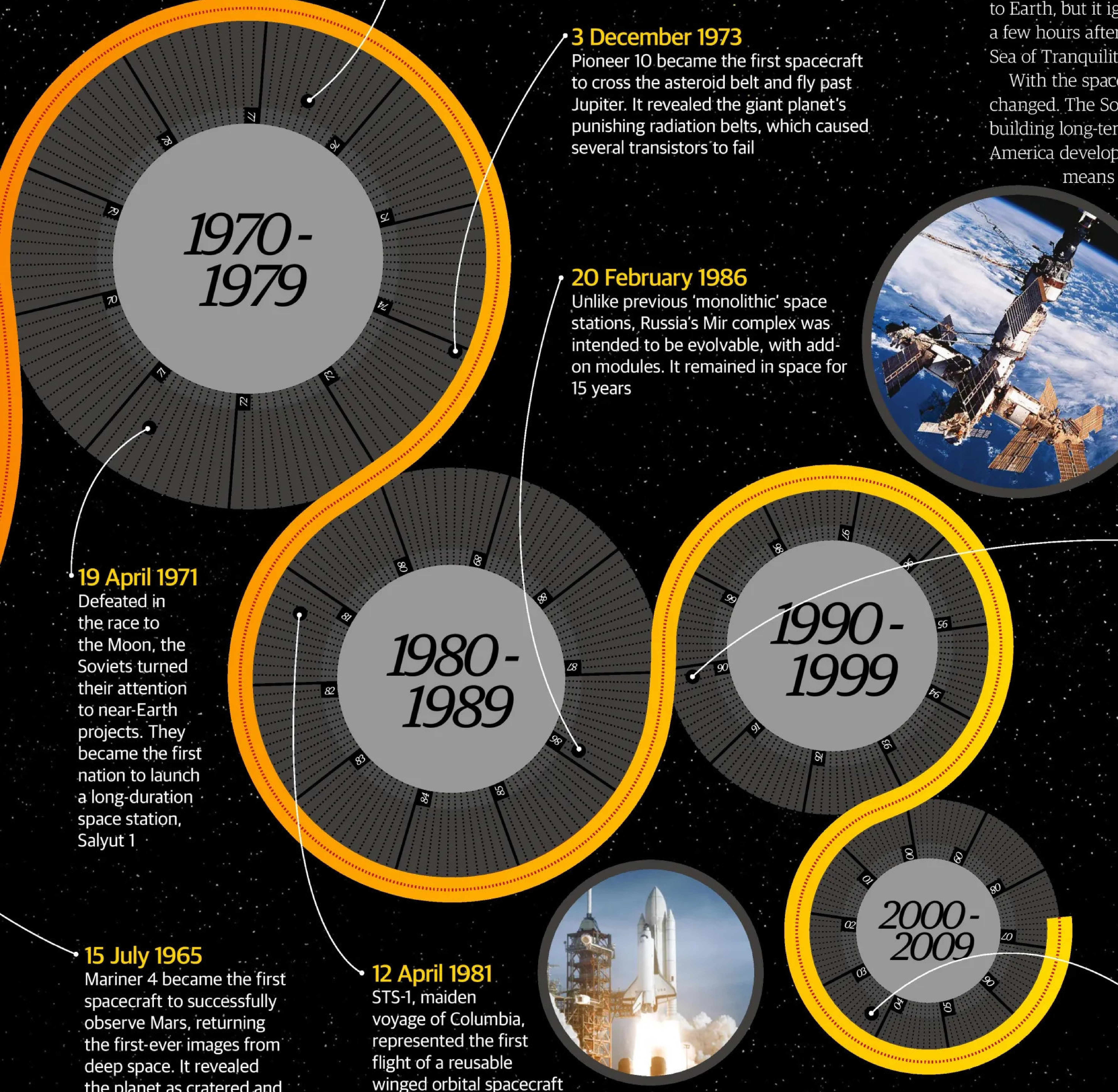
Eventually, the two former foes united their efforts in today's International Space Station. And aboard that station on the 60th anniversary of Sputnik 1's success, astronaut Joe Acaba was filled with wonder for the past and excited hope for the future. "Amazing to be on Space Station and reflect on how far we've come," he tweeted. "What will the next 60 years bring us?"

**24 December 1968**
On Christmas Eve 1968, Apollo 8 astronauts Frank Borman, Jim Lovell and Bill Anders observed 'Earthrise' from behind the limb of the Moon, for the first time

**20 July 1976**
Seven years after the first manned Moon landing, Viking 1 became the first spacecraft to soft-land on the surface of Mars and successfully completed its mission



**3 December 1973**
Pioneer 10 became the first spacecraft to cross the asteroid belt and fly past Jupiter. It revealed the giant planet's punishing radiation belts, which caused several transistors to fail



**20 February 1986**
Unlike previous 'monolithic' space stations, Russia's Mir complex was intended to be evolvable, with add-on modules. It remained in space for 15 years

**14 February 1990**
From the very edge of the Solar System, Voyager 1 acquired a 'family portrait', showing six of the then-known planets, minus Mercury, Mars and the dwarf world Pluto

**19 April 1971**
Defeated in the race to the Moon, the Soviets turned their attention to near-Earth projects. They became the first nation to launch a long-duration space station, Salyut 1

**15 July 1965**
Mariner 4 became the first spacecraft to successfully observe Mars, returning the first-ever images from deep space. It revealed the planet as cratered and geologically dead

**12 April 1981**
STS-1, maiden voyage of Columbia, represented the first flight of a reusable winged orbital spacecraft with humans aboard. It marked the dawn of a 135-flight career for the shuttle fleet

**15 October 2003**
Taikonaut Yang Liwei became the first Chinese spacefarer when China launched the Shenzhou 5 spacecraft, and became the third nation to launch its own personnel into orbit

# The beginning of NASA: Project Mercury

Project Mercury was the first major project NASA embarked on, as the Space Race with the Soviets intensified

The start of NASA's longstanding presence in space began with Project Mercury. Without this project, the Apollo missions that took mankind to the Moon never would have happened. On 7 October 1958, when NASA was only a few months old, Project Mercury was officially unveiled as NASA's first major project. It had three very clear aims as the US went head-to-head with the Soviet Union in the Space Race. First, NASA wanted to be able to place a human in orbit around Earth successfully; second, they wanted to understand how space flight affects the human body, and last they wanted to be able to return both the astronaut and space vessel safely back to Earth.

Before NASA could send anyone to space, the team of America's first future astronauts had to be found and the Mercury space capsule had to be designed and brought into existence. The Mercury space capsule was only big enough to fit a single person inside, but it had everything in it for one to survive and was an engineering masterpiece at the time. The cone-shaped capsule had a series of parachutes, boosters, vital supplies (e.g. water, oxygen etc), an antenna, a heatshield and a room that would accommodate the astronaut on their journey and ensure a safe return back to the surface.

But who was to going to fill these capsules? On 9 April 1959, the NASA administrator under President Eisenhower, Thomas Keith Glennan, announced the seven pioneers that would battle it out against the Soviets in a press conference in Washington DC, United States. Malcolm Scott Carpenter, Leroy Gordon Cooper Jr, John Herschel Glenn Jr, Virgil Ivan (Gus) Grissom, Walter Marty Schirra Jr, Alan Bartlett Shepard Jr and Donald Kent Slayton were the chosen soldiers and were henceforth known as 'Mercury Seven'. The selection process for these astronauts was extremely strict as the NASA committee in charge of astronaut selection were well aware of the unusual conditions of spaceflight. The committee decided to single out military test pilots who thrived in high-performance aircraft and had shown as much with a lot of flying experience, a piece of criteria that excluded the likes of Neil Armstrong, the first man to step on the Moon as part of Apollo 11. After a series of extreme physical, psychological and mental examinations, 110 candidates were narrowed down to these seven. Within the rejected 103 were people that would later successfully go through Gemini and Apollo missions, but in this instance, they couldn't make the cut. These figures included the likes of Jim Lowell of Apollo 8, who didn't pass the medical tests, and Pete Conrad, who was the third man to walk on the Moon as part of Apollo 12, and who didn't want to endure any more invasive medical tests. The Mercury Seven men went on to have distinguished careers with NASA, but at the time they immediately shot to fame. The heady combination of the fact that the United States was in an intense space race, and tales of the exotic training and experiences that lay ahead for these astronauts, saw public interest in these men reach a new height.

The training that the Mercury Seven underwent shaped the procedures that would later have a heavy influence on the Apollo mission. This training program was split into five major categories consisting of basic astronautical science instruction,

President Kennedy toured NASA's Cape Canaveral site several times. The Launch Operations Center was renamed the John F Kennedy Space Center after his death

A Marine helicopter picks up Mercury astronaut Alan Shepard and his Freedom 7 capsule

> "Alan Shepard became the first American in space after completing a historic 15-minute sub-orbital flight"

systems training, spacecraft control training, environmental familiarisation, and egress and survival training. The tests that the Mercury Seven crew underwent were also taken by 13 women behind closed doors, and led by William Randolph Lovelace, who was the chairman of NASA's Special Advisory Committee on Life Science. This privately-funded programme showed that these women could not only pass the tests the Mercury Seven crew went through, but some even surpassed their male rivals. However, NASA's requirement that would-be astronauts be highly qualified jet pilots automatically excluded them from participation in the fledgling space programme. The First Lady Astronaut Trainees, or the Mercury 13 as they were later dubbed, began a fight for woman's rights and against prejudice and discrimination, which they eventually won. The Soviet space programme, however, put the first woman into space in 1963. An American woman would not go up until 20 years later.

In order to test the Mercury space capsules as well as the two launch vehicles that were going to take the first Americans into space, Atlas and Redstone, NASA performed unmanned missions; some empty and some containing animals. These valiant creatures include the likes of a rhesus monkey named Sam, and two chimpanzees named Ham and Enos. The Mercury-Redstone rocket was designed to take humans to a sub-orbital flight, whereas the Atlas rocket would put humans into a low-Earth orbit.

On the 5 May 1961, 23 days after Russian cosmonaut Yuri Gagarin became the first person in space after a 108-minute flight, Alan Shepard became the first American in space after completing a historic 15-minute sub-orbital flight in space as part of the Freedom 7 mission. Shepard also went on to be the spacecraft commander of Apollo 14, and became the fifth man to walk on the Moon. This mission was repeated on 21 July 1961 so that NASA could again study and improve human spaceflight. Gus Grissom flew the Liberty Bell 7 mission, which saw two changes to the previous space capsule. This capsule had an explosively actuated side hatch and a viewing mirror, as requested by the Mercury astronauts. After another 15 minutes in space, the Liberty Bell 7 hatch blew out early and Grissom hit the Atlantic Ocean, with water quickly flooding the vessel. For a moment, Grissom almost drowned, but he managed to escape Liberty Bell 7 and was rescued after only a few minutes of being out in the ocean. Unfortunately, Grissom was one of the unlucky three people that later perished in a flash fire during Apollo 1 tests.

After the Redstone missions had been completed, the United States was still playing catch-up with the Soviet Union as they had more people in space and had logged more time in space at this point. The first manned spaceflight of the Atlas launch vehicle was on 20 February 1962, with John Glenn riding in the Friendship 7 spacecraft. This mission lasted for almost five hours in space, travelling at an altitude of 260 kilometres (162 miles), thus making Glenn the first American to orbit the Earth, which he did three times. Glenn had a very interesting career post-Mercury, as after he left NASA, he became a US Senator and then later returned to NASA in 1998 to become the oldest person to ever fly in space at the age of 77 as part of the STS-95 crew.

The Project Mercury flights that took place after this were performed purely as research operations, in order to push the boundaries of human space flight and understand how it affects the human body. On 24 May of the same year, Carpenter had his turn to fly in space. Aurora 7, as it was named, was a replicated mission that covered an equal time in space and simply confirmed the success of Friendship 7. This mission should have been Slayton's turn, however a couple of months before the launch he was ruled out on the grounds of a medical condition called idiopathic atrial fibrillation, which meant he had an erratic heart rate. Slayton still went on to have a great career as

Ham the chimpanzee was the first non-human hominid launched into space. He was trained to push buttons to test his reactions while in orbit

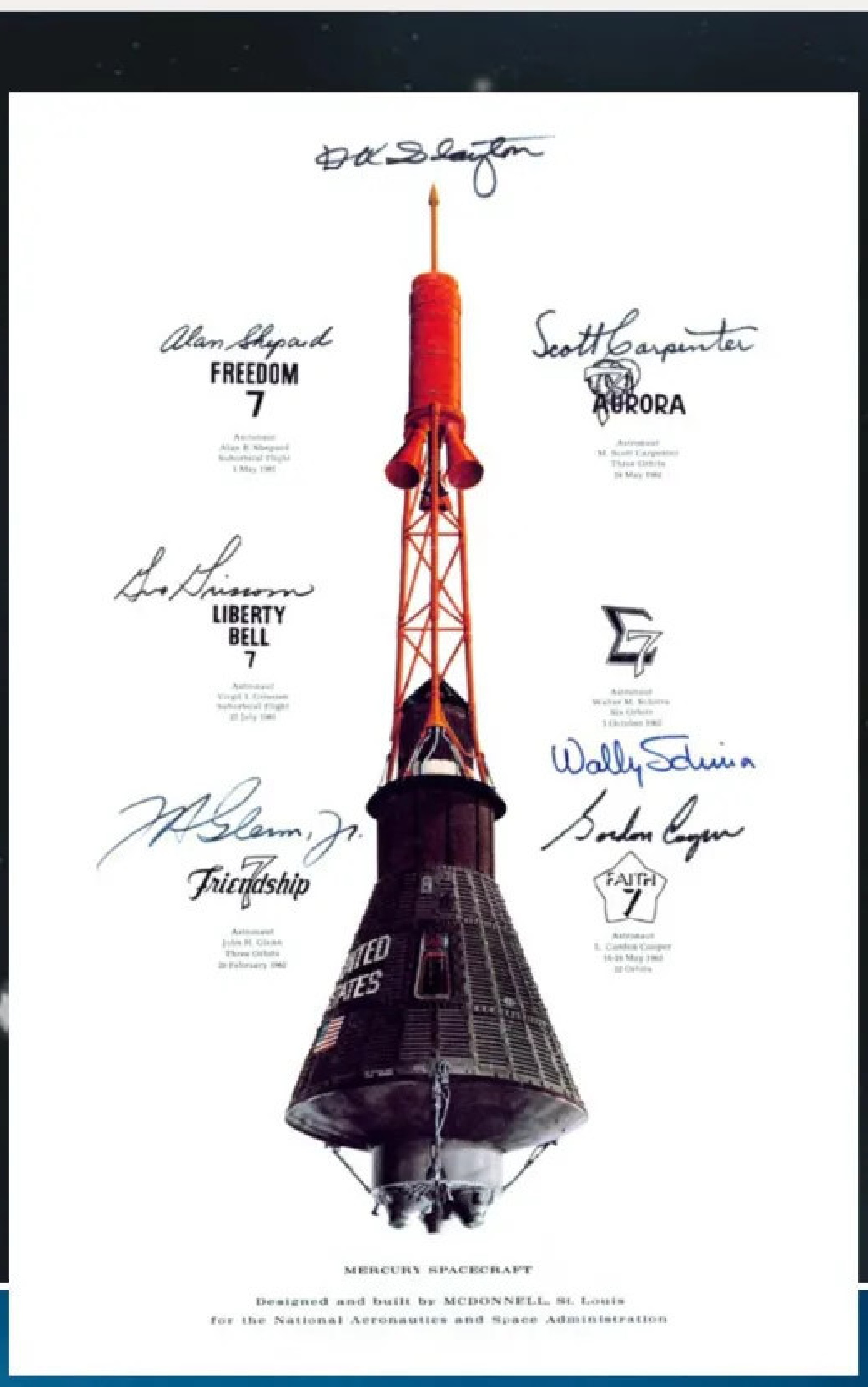
This monument at Pad 14, Cape Canaveral, commemorates Project Mercury

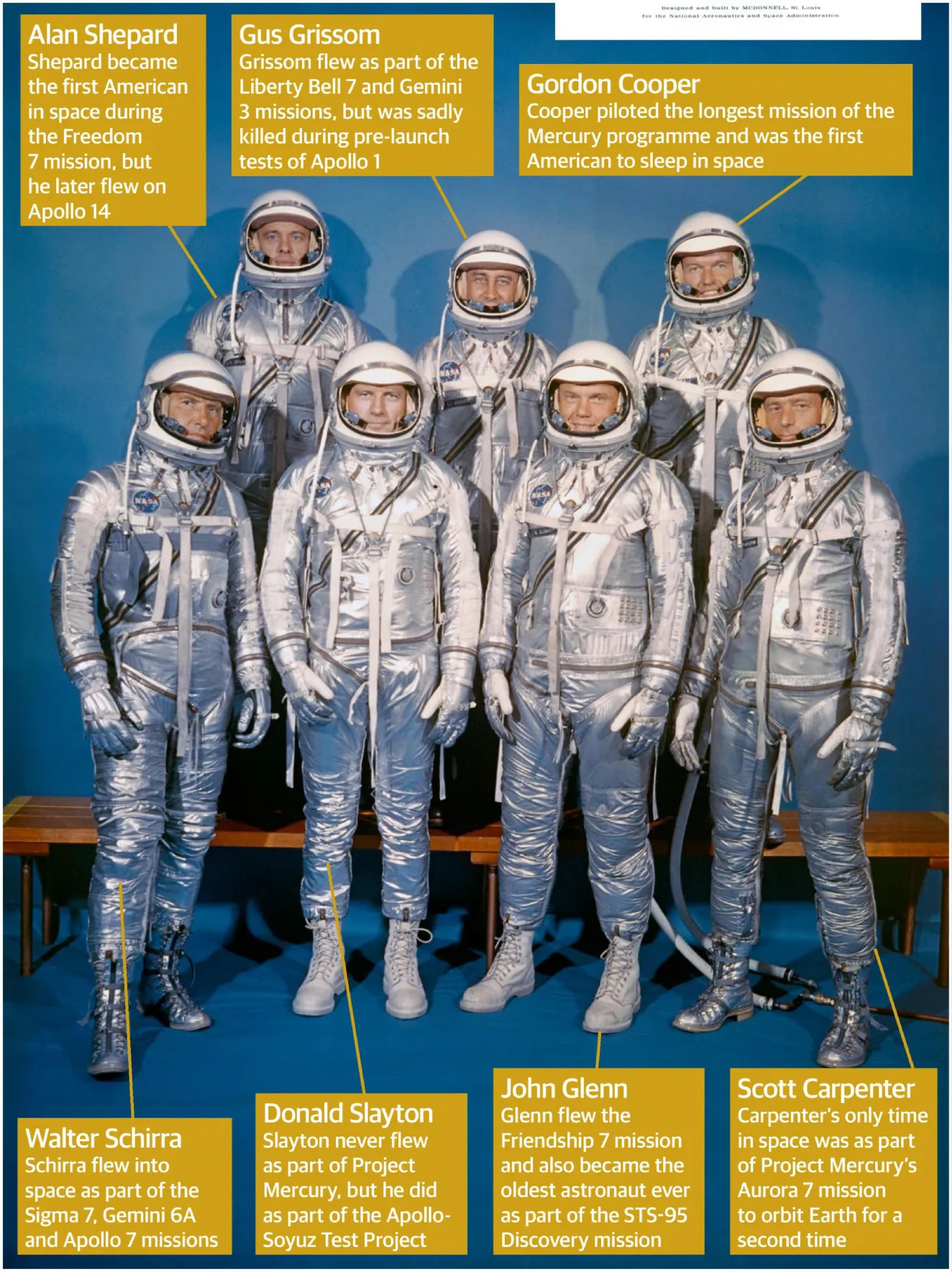
an astronaut, participating in the Apollo-Soyuz test project that marked the end of the Space Race.

On 12 September, John F Kennedy made his famous speech that stated the United States was heading for the Moon. So from then on, Project Mercury was all about increasing the intensity of spaceflight and seeing how long an astronaut could stay in space for, which helped the preparation for a mission to the Moon. Sigma 7 was undertaken by Schirra on 3 October; he spent a total of nine hours in space and orbited the Earth six times. This was a good indicator that the United States was moving in the right direction. The last mission, the mission that would close the curtain on the outstanding Project Mercury, was undertaken by Cooper on board the Faith 7 space vessel. Cooper spent 34 hours in space so that scientists could evaluate the effects of over a whole day in space, a time that seemed inconceivable at the time of Shepard's flight. Both Cooper and Schirra went on to be heavily involved in Project Gemini, and Schirra even went on to be commander of Apollo 7. The collective efforts of everyone involved with Project Mercury were fundamental to humanity exploring the next frontier, the Moon, and Project Mercury was followed swiftly by Project Gemini, which was formally conceived in January 1962.

# The history of Project Mercury

The insignias from the six manned missions and the signatures of the seven Mercury Seven crewmembers surround the United States' first spacecraft, the Mercury spacecraft. These six missions had times in space that started at just 15 minutes and finished with an astonishing 34-hour mission, completing 22 orbits of Earth.


FREEDOM 7
AURORA
LIBERTY BELL 7
Friendship 7
FAITH 7
MERCURY SPACECRAFT
Designed and built by McDONNELL, St. Louis for the National Aeronautics and Space Administration



**Alan Shepard**
Shepard became the first American in space during the Freedom 7 mission, but he later flew on Apollo 14

**Gus Grissom**
Grissom flew as part of the Liberty Bell 7 and Gemini 3 missions, but was sadly killed during pre-launch tests of Apollo 1

**Gordon Cooper**
Cooper piloted the longest mission of the Mercury programme and was the first American to sleep in space

**Walter Schirra**
Schirra flew into space as part of the Sigma 7, Gemini 6A and Apollo 7 missions

**Donald Slayton**
Slayton never flew as part of Project Mercury, but he did as part of the Apollo-Soyuz Test Project

**John Glenn**
Glenn flew the Friendship 7 mission and also became the oldest astronaut ever as part of the STS-95 Discovery mission

**Scott Carpenter**
Carpenter's only time in space was as part of Project Mercury's Aurora 7 mission to orbit Earth for a second time

© NASA

# Learning to fly

## Project Gemini formed a bridge between NASA's first Mercury flights and the Apollo Moon programme

The historic flight of Soviet cosmonaut Yuri Gagarin on 12 April 1961 plunged the United States into a crisis of confidence – if their Cold War rival was so far ahead in space, what else might they be capable of? The Mercury programme would be America's immediate response, but President John F Kennedy realised that a long-term solution was needed, refocusing US space policy on an ambitious target that would, over several years, allow NASA to fight its way back into the Space Race. Six weeks later, Kennedy announced a new goal in space to Congress – America was going to the Moon.

NASA officials knew that getting there would call for an array of new techniques and technology. Aside from powerful new rockets, potential schemes for putting people on the Moon all required rendezvous and docking of spacecraft and components in orbit – flight manoeuvres far beyond the Mercury capsule's basic capabilities.

With the Apollo spacecraft still on the drawing board, there was a clear need for an intermediate vehicle – something capable of supporting more than one astronaut on longer missions, manoeuvring in orbit and testing various procedures that might be needed en route to the Moon. This new spacecraft was to be Project Gemini.

Once the basic requirements had been established, the Gemini spacecraft was developed and built at breakneck speed. Although superficially similar in appearance to a scaled-up Mercury capsule, it was far more capable. A pressurised 're-entry module' seated two astronauts side-by-side in a cockpit environment that was designed in consultation with the Mercury astronauts (particularly Gus Grissom) and appealed to their test-pilot mindset.

Beneath this in a conical stack sat two more elements – the 'retrograde module' whose rockets would be used to return from orbit, and the 'equipment module' carrying batteries, propellant, water and other supplies. An important advance came with the introduction of fuel-cell technology that could generate electricity using liquid oxygen and hydrogen, reducing the need for heavy batteries and permitting longer-duration flights. Thruster nozzles dotted across the surface of all three elements allowed a Gemini craft to change its orbit and orientation in space.

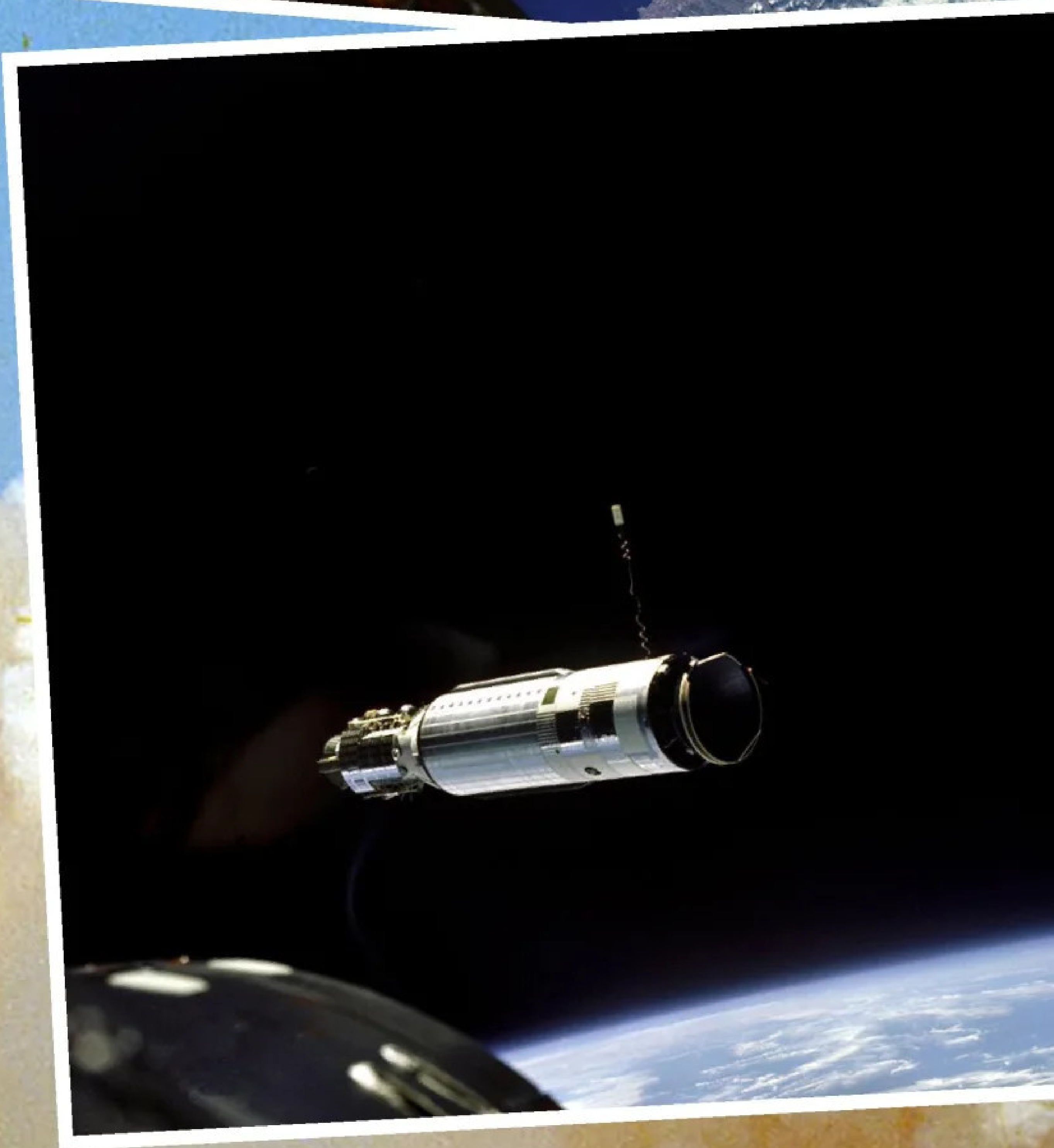
The first Gemini spacecraft was launched on 8 April 1964 using a Titan II rocket. This derivative of the US Air Force's Titan ballistic missile, a fairly simple and reliable rocket whose fuels ignited on contact (avoiding the need for a complex ignition system), was used for launches throughout the Gemini programme.

Fitted with test equipment in place of a crew, the Gemini 1 spacecraft appeared to perform well in orbit, but was not designed for recovery. A second test, in January 1965, assessed the splashdown procedure and allowed engineers to see how the spacecraft had coped with re-entry to the atmosphere.

With no significant problems encountered, NASA gave the go-ahead for a manned launch. Gemini 3 launched on 23 March 1965, pairing Grissom with a new astronaut, John W Young. The shakedown flight lasted a mere three orbits, but the spacecraft systems worked perfectly and the only significant incident occurred when Young produced a corned-beef sandwich he had smuggled aboard, sharing a few bites with Grissom. Despite being reprimanded by his superiors afterwards, Young would go on to have an illustrious NASA career, flying in both the Apollo and Space Shuttle programmes.

The path was now clear for a more ambitious mission in the form of Gemini 4. Crewed by two new astronauts, James McDivitt and Ed White, this June flight lasted a little over four days. During the mission, the astronauts successfully carried out a range of on-board experiments, although attempts to change

UNITED STATES



orbit and rendezvous with the spacecraft's own Titan II upper stage ended in failure.

However, such problems were outshone by an iconic success, as White opened his hatch and became the first US astronaut to walk in space. White remained tethered to the spacecraft throughout his 'Extra-Vehicular Activity' (EVA), but he was able to float free and manoeuvre using a 'zip gun' that fired a jet of gas in one direction to push him in the other. Although the Soviets had achieved their first spacewalk a few months before, White's longer EVA went far more smoothly, and delivered stunning photographs of an astronaut floating in space – at last, it seemed, NASA was catching up in the Space Race.

That message was reinforced when Gemini 5, launched in August 1965, spent eight days in orbit, smashing the five-day space endurance record previously held by the Soviet Vostok 5. The mission paired Mercury veteran L Gordon Cooper with newcomer Charles "Pete" Conrad Jr, and was the first to match the duration of the planned lunar flights. Not everything went smoothly, however – issues with the fuel cells meant electricity had to be rationed – a planned rendezvous with an unmanned 'pod' was scaled back to a more basic manoeuvring test, and other experiments had to be abandoned (leading Conrad to remark at one point that he wished he'd brought a book with him to pass the time).

Gemini 7 as seen from Gemini 6 during the first US rendezvous in space

"Gemini 5 spent eight days in orbit, smashing the five-day space endurance record previously held by the Soviets"

Although many aspects of Gemini had now proved successful, pressure was mounting for the next mission to pull off the long-awaited orbital rendezvous. Gemini 6, planned for launch on 25 October, was intended to rendezvous with a special unmanned 'Agena target vehicle' (ATV) that would launch shortly ahead of it. Mercury astronaut Wally Schirra and his colleague Thomas Stafford were sitting aboard their spacecraft ready for launch when news came through that the ATV had been lost after an explosion.

With Gemini 7 already planned for a December launch on a 14-day endurance mission, it seemed that Gemini 6 had lost its launch window, and the opportunity for a successful rendezvous would have to wait until the following year. But then Frank Borman and Jim Lovell, the Gemini 7 crew, made a daring suggestion: why not use their own spacecraft as Gemini 6's rendezvous target? After some convincing, NASA officials signed off on the idea – Gemini 6 (redesignated Gemini 6-A) launched on15 December, towards the end of Borman and Lovell's mission. And this time, everything went smoothly, with Schirra and Stafford steering their capsule to within 30 cm (12 in) of Gemini 7.

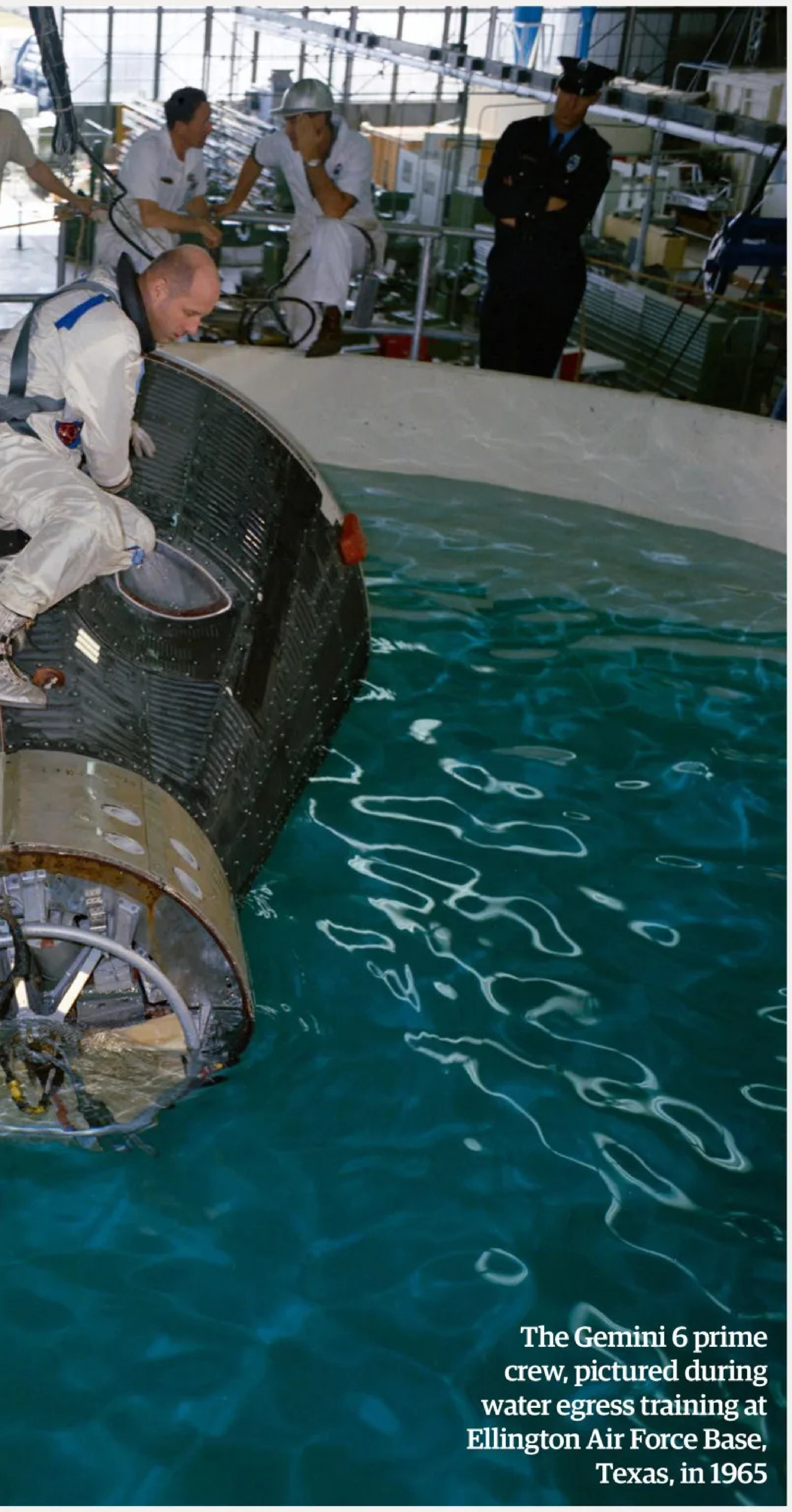
1966 saw ever-more daring missions for Gemini, as NASA geared up for the planned first flights of the Apollo spacecraft the following year. Gemini 8, launched in March, was crewed by two newcomers who would both go on to command Apollo lunar missions – Neil Armstrong and David Scott. They docked successfully with an ATV at last (the first ever docking in orbit), but shortly afterwards a jammed thruster set the linked spacecraft into a dangerous spin that forced them to cut the mission short.

Gemini 9-A (the designation indicated the use of its reserve crew, Thomas Stafford and Gene Cernan, after the primary crew died in an air crash) also hit a number of problems. When the spacecraft approached

its ATV docking target in June, it found that the protective shroud around it had failed to come away, making docking impossible. Cernan also had trouble accessing an 'astronaut manoeuvring unit' jetpack that he was supposed to wear during a spacewalk.

Fortunately, this was the programme's last major setback. Gemini 10, launched the following month with John Young and Michael Collins aboard, not only docked with its own ATV, but then steered to a rendezvous with the Gemini 8 target vehicle, allowing Collins to inspect the abandoned spacecraft during an EVA. Gemini 11 saw Pete Conrad and Richard Gordon set a new altitude record of 1,374 km (854 miles), and even generated artificial gravity by tethering the spacecraft and its ATV, then setting them in a slow spin around each other.

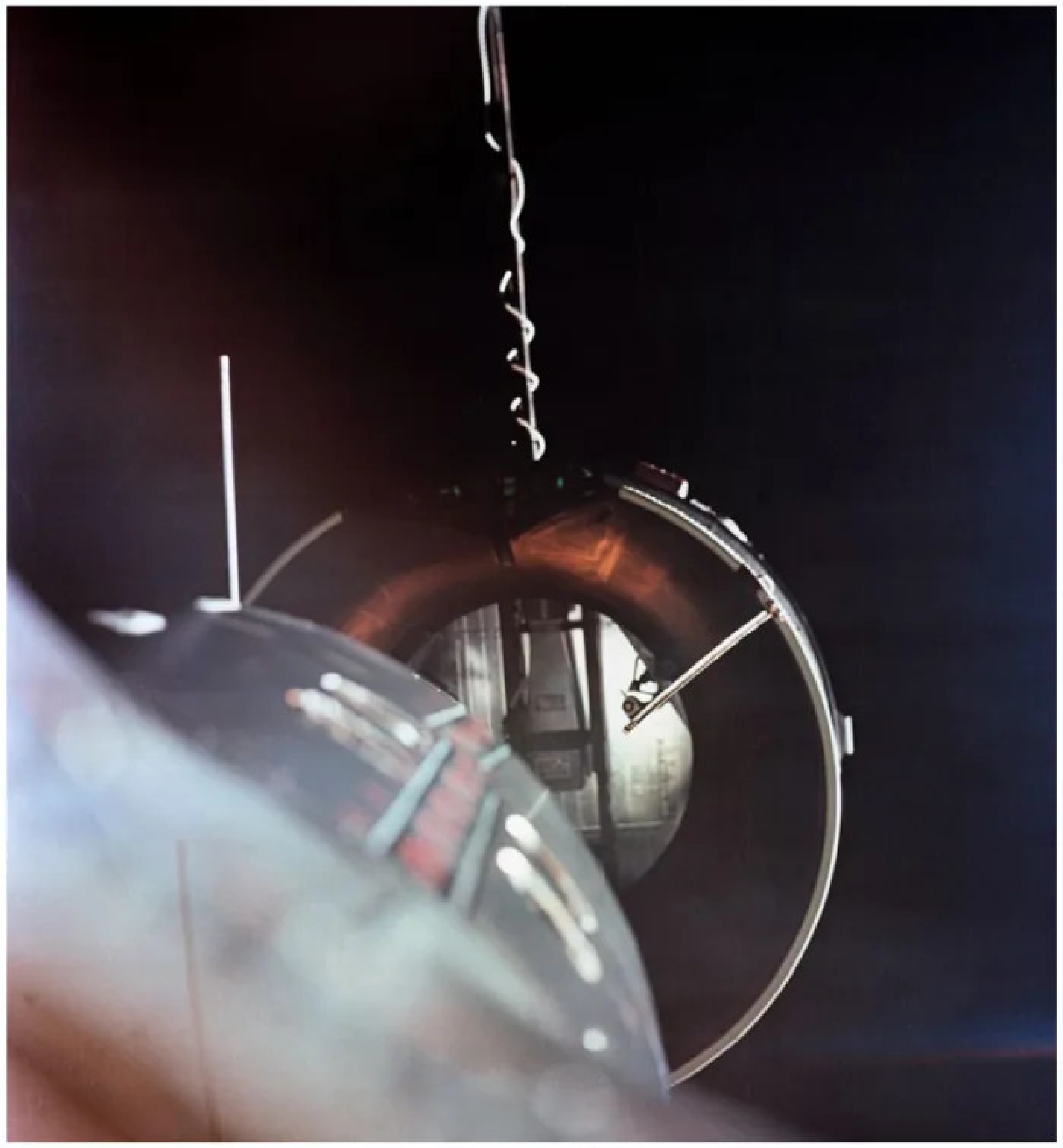
The twelfth and final Gemini mission was brief but equally ambitious. Crewed by Buzz Aldrin and Jim Lovell, it spent four days in orbit rehearsing many of the docking and rendezvous techniques that would be required by the Apollo missions. In addition, Aldrin carried out a complex two-hour spacewalk using new handgrips to clamber around the capsule and practice servicing it in space. By the time Gemini 12 splashed down on 15 November 1966, the stage was set for the debut of Apollo.

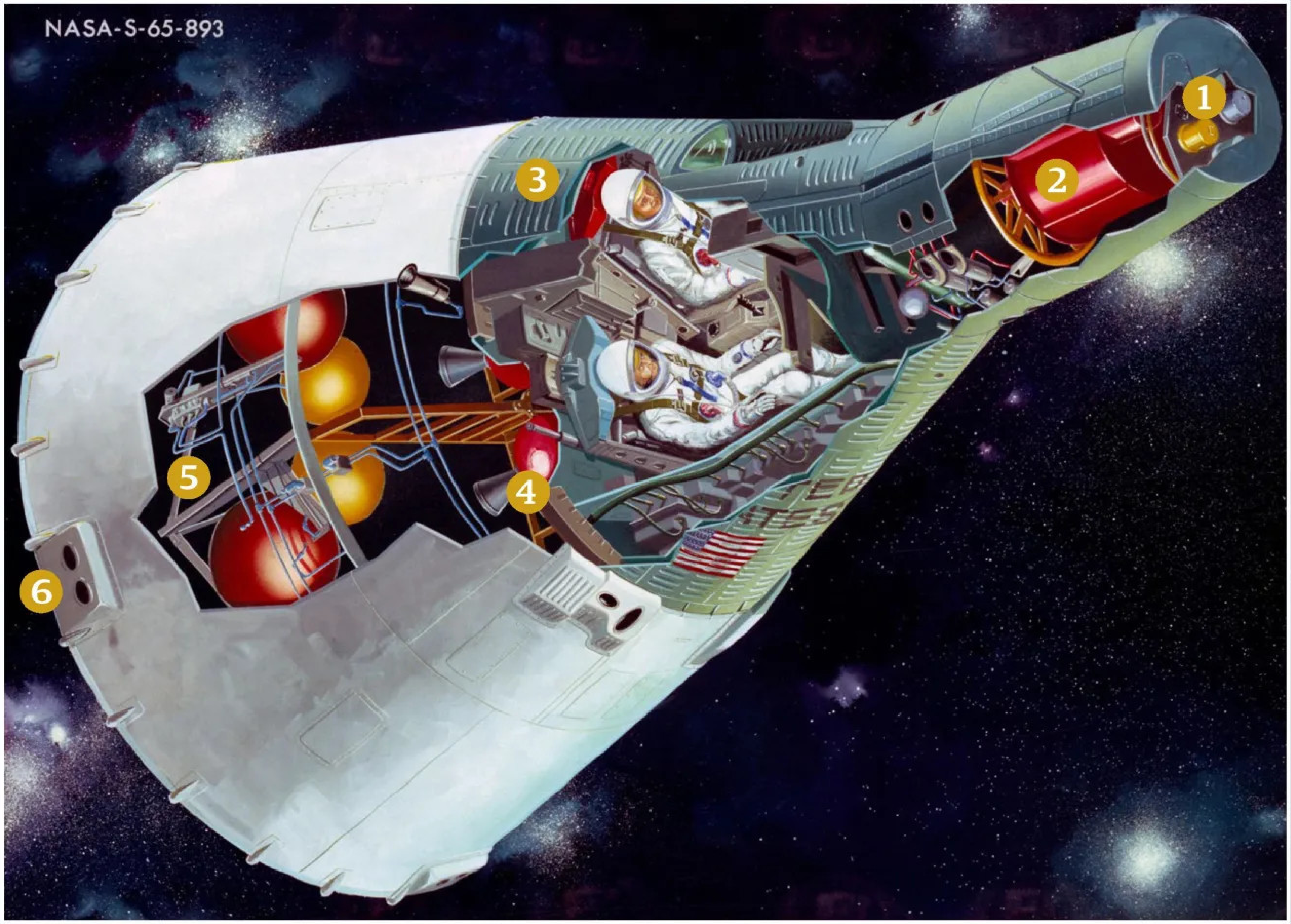


The Gemini 6 prime crew, pictured during water egress training at Ellington Air Force Base, Texas, in 1965

## Docking in space

Gemini's docking system consisted of a probe mounted on the end of the manned spacecraft that locked into a conical receptor on the end of the target vehicle. Gemini 11 pilot Richard Gordon compared it to the mid-air refuelling mechanism on a jet fighter. Once securely docked, controls in the Gemini capsule allowed the astronauts to control the engine and thrusters on the target vehicle.





### 1 Rendezvous antenna

This antenna extended from the spacecraft during docking operations and slid into a cone on the target vehicle.

### 2 Parachute system

During re-entry, Gemini employed a small drogue before its main parachutes – early plans to use a paraglider system were abandoned.

### 3 Crew hatches

Twin hatches allowed access for the astronauts – EVAs were carried out simply by the astronaut opening the hatch and standing up in his seat.

### 4 Retrograde module

Situated behind the re-entry module, the retro module housed four solid rockets. During re-entry, the spacecraft reversed its orientation to point backwards along its orbit, and fired these rockets to slow down.

### 5 Equipment module

The rearmost Gemini module contained equipment to power and sustain the spacecraft on missions that were going to be up to two weeks long, including batteries and fuel cells, water and oxygen.

### 6 Attitude control thrusters

Thrusters positioned at various points around the Gemini spacecraft could be fired in sequence to change the vehicle's orientation and manoeuvre in space.

© NASA, KSC, James McDivitt

# Gemini 8: Mission abort

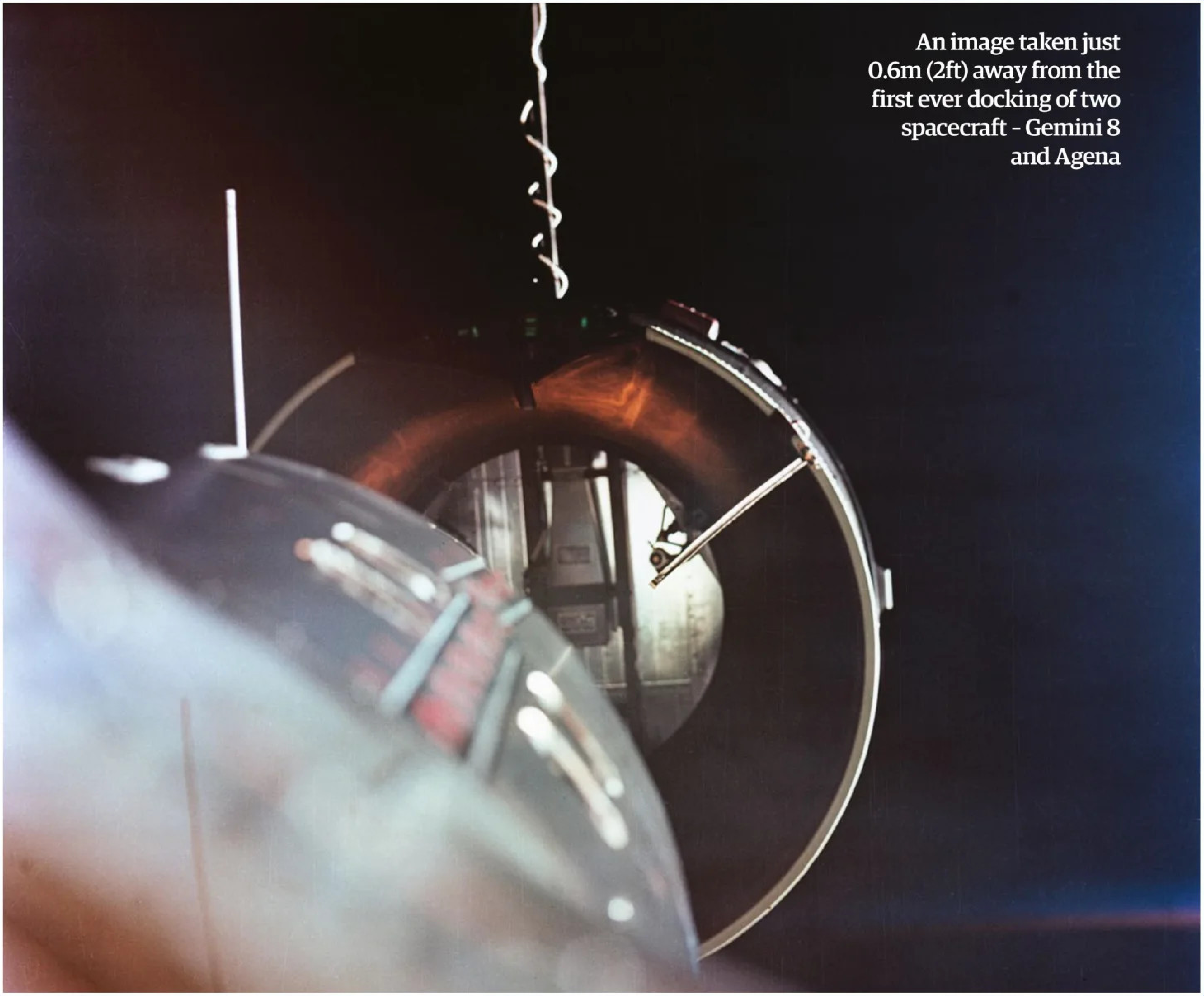
## From successfully docking two crafts in space to a horrifying, stomach-turning problem...

Neil Armstrong was the first person to walk on the Moon, but Apollo 11 in 1969 was not his first foray into space. On 16 March 1966, NASA launched the two-man, three-day Gemini 8 mission from Cape Kennedy (now Cape Canaveral). Armstrong was the commander and, together with David Scott, spent more than six hours performing nine manoeuvres to rendezvous with the unmanned Gemini Agena Target Vehicle, which launched earlier in the day.

Having completed the first ever successful docking in orbit of two vehicles, control of Gemini 8 was transferred to Agena. At this point, Scott should have begun preparing for an extravehicular activity (EVA) to retrieve a nuclear radiation experiment from the front of Gemini's spacecraft adapter and in order to activate a micrometeoroid experiment on the Agena. Instead, however, disaster struck within just 30 minutes of Gemini 8 docking with the Agena Target Vehicle.

The combined spacecraft had veered 30 degrees off the horizon and couldn't be corrected. A malfunctioning thruster sent the vehicle violently tumbling and twisting around its vertical axis. When control was returned to Gemini, it yawed, rolled and pitched, faster and faster. Even as Gemini was disengaged, it revolved once every second.

With the crew in danger of blacking out, the mission was aborted and the re-entry system activated. This stabilised the spacecraft and allowed Gemini to land in the sea 1,000 kilometres (621 miles) south of Yokosuka in Japan. It was a disappointment that the mission had to be aborted, but at least – ten hours and 44 minutes after launch – Armstrong and Scott were safely back on Earth.



An image taken just 0.6m (2ft) away from the first ever docking of two spacecraft – Gemini 8 and Agena

Neil Armstrong and David Scott await the recovery ship following splashdown of Gemini 8 after the mission was aborted

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# Project Apollo

## NASA's groundbreaking effort to reach the Moon

**1961-1966**

### SA and AS unmanned missions

In preparation for the manned Moon missions, NASA conducted a series of tests using various iterations of the Saturn rocket, in order to practice launch, Low Earth Orbit, re-entry and mission aborts.

**27 January 1967**

### Apollo 1

See page 40

**9 November 1967**

### Apollo 4

After Apollo 1's launch test disaster, the nomenclature of subsequent missions was changed. No Apollo 2 or 3 existed; the next mission in the programme, a Type-A unmanned flight, was the first test of the Saturn V rocket that would eventually take man to the Moon.

**22 January 1968**

### Apollo 5

The next unmanned mission was a Type-B on a Saturn IB rocket and marked the first flight of the Lunar Module, including successful tests of its ascent and descent engines, and a simulation of a landing abort, referred to as a 'fire-in-the-hole' test by NASA engineers.

**4 April 1968**

### Apollo 6

The final unmanned Apollo mission was used to test the Saturn V's ability to propel the spacecraft into trans-lunar injection (TLI). The flight experienced problems from the start, including a vibration problem called pogo oscillation that damaged the fuel lines. It was also the only Saturn V-launched Apollo flight with a white Service Module - all the others were silver in colour.

**11 October 1968**

### Apollo 7

See page 42

**21 December 1968**

### Apollo 8

See page 46

**3 March 1969**

### Apollo 9

See page 48

**18 May 1969**

### Apollo 10

See page 52

**16 July 1969**

### Apollo 11

See page 54

### 14 November 1969

**Apollo 12**

Apollo 12 was a stormy flight. It launched amid thunder and was struck by lightning, which overloaded the telemetry systems and caused them to fail. Flight controller John Aaron had seen this error happen before in a simulation, leading him to give the unusual command "Apollo 12, Houston. Try SCE to Auxiliary. Over", which confused two of the three astronauts aboard. Lunar Module pilot Alan Bean, however, remembered a similar simulation from his own training and knew where the obscure switch was located. He flipped the systems to a backup power supply as per Aaron's request, and the telemetry data come back online. With the problem solved, the flight went on to make the first precision lunar landing in – where else? – the Ocean of Storms.

### 11 April 1970

**Apollo 13**

See page 62

### 31 January 1971

**Apollo 14**

See page 64

### 26 July 1971

**Apollo 15**

See page 66

### 16 April 1972

**Apollo 16**

The first mission to land in the lunar highlands, Apollo 16's flight was largely textbook, despite a launch delay due to technical problems. The crew conducted three moonwalks on the lunar surface, totalling more than 20 hours and exploring both on foot and in the lunar rover, and conducted experiments on the Moon and in space on their return journey home, including deploying a small subsatellite that was intended to orbit the Moon but crashed into its surface just 35 days later, inadvertently leading NASA to the realisation that there are only four so-called 'frozen' lunar orbits in which an object can orbit the Moon indefinitely, at 27, 50, 76 and 86-degrees inclination: gravitational anomalies called mascons drag objects in other low lunar orbits inexorably towards the Moon's surface.

### 7 December 1972

**Apollo 17**

The last official flight of the Apollo programme broke several records: for the longest time in lunar orbit, the largest sample brought back from a mission, the longest total moonwalks, and the longest Moon landing itself. It was also the first time that NASA had launched a manned spacecraft at night. Sadly, it also currently holds the dubious honour of being the last time humans visited the Moon.

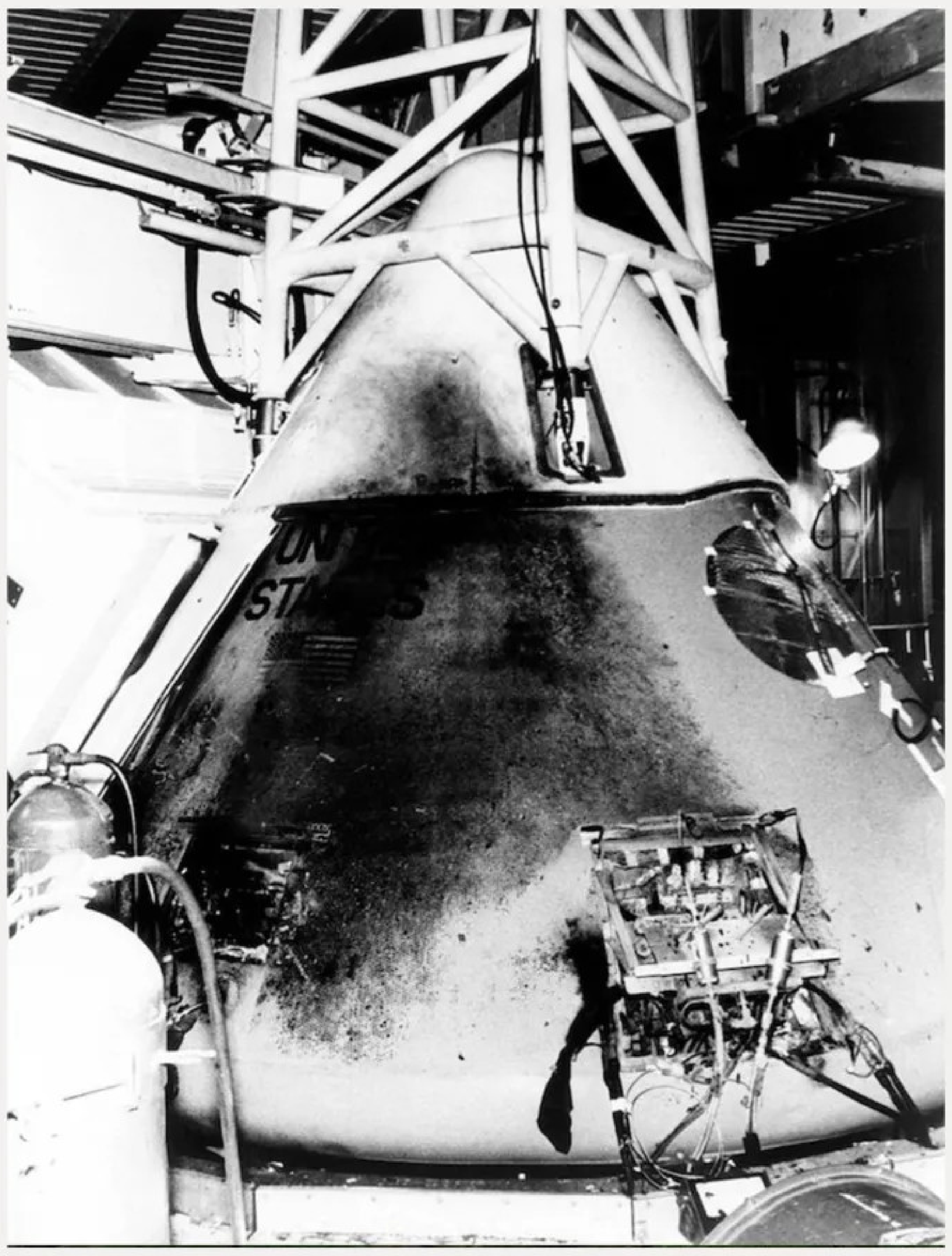
# Fire in the cockpit

## A catastrophic flash fire killed three astronauts and nearly ended the Apollo programme that was intended to reach the Moon

Reaching the Moon was the raison d'etre for NASA, and America's space agency raced headlong toward that goal. AS-204, the first manned mission of the Apollo program, was scheduled for liftoff on 21 February 1967, intended to take three astronauts into orbit.

Now, after preliminary work in the Mercury and Gemini programs, Apollo would eventually take mankind to the Moon, as President John F Kennedy had challenged the nation to accomplish before the end of the 1960s. On 27 January 1967, however, AS-204 came to grief. Three astronauts died in a tragic fire at Launch Complex 34 in Cape Canaveral, Florida. The accident occurred during a 'plugs out integrated test' of systems and procedures operating as nearly as possible to actual flight conditions, including a simulated launch.

The three astronauts, command pilot Virgil I 'Gus' Grissom, age 40, senior pilot Ed White, 36, and pilot Roger B Chaffee, 31, perished inside the command module within 30 seconds of the first indication of fire, due to smoke inhalation and burns. Training for his third mission, Grissom, an Air Force lieutenant colonel, had participated in the Mercury and Gemini programmes. White, also an Air Force lieutenant colonel, had piloted Gemini 4, becoming the first American to walk in space. Chaffee, a US Navy lieutenant commander, was anticipating the experience of his first space flight.

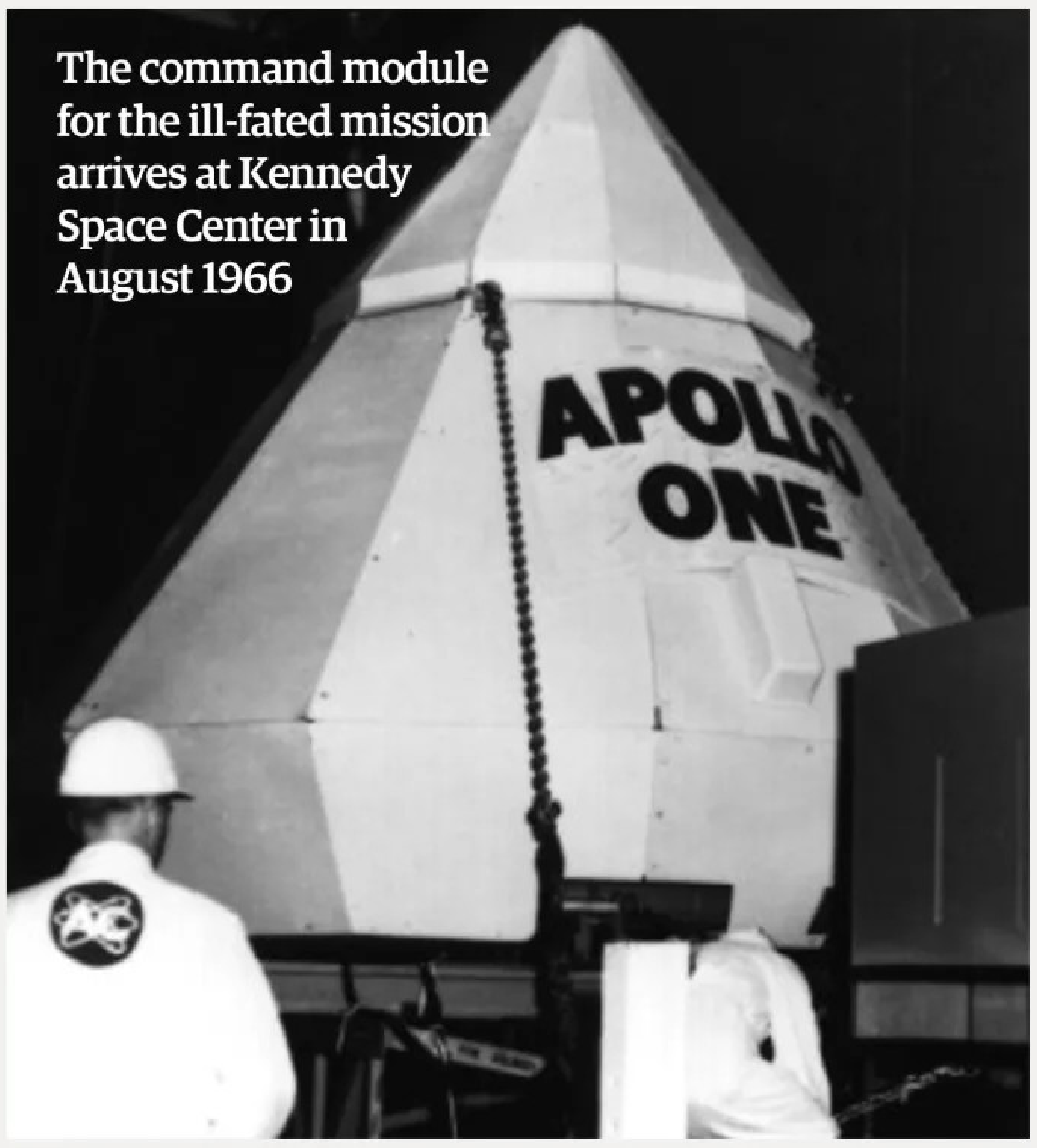


Prior to the test date, the astronauts themselves had noted concerns regarding the readiness of the command module. During a meeting in August 1966, the crew had expressed misgivings about the copious amount of flammable material in the cockpit to aerospace engineer Joseph F Shea, the Apollo Spacecraft Program Office manager. Shea ordered the flammable materials removed but did not personally supervise the operation. At the time of the accident, both adhesive Velcro and nylon netting were present in command/service module CM-012. Shea deemed the spacecraft safe, but the crew posed for a photograph with their hands clasped and heads bowed in prayer. The accompanying inscription read: "It isn't that we don't trust you, Joe, but this time we've decided to go over your head."

Grissom's frustration grew steadily, and during a visit to his home in Texas five days before the tragedy he pulled a lemon from a tree in his backyard. When he returned to Cape Canaveral, he hung the lemon from the flight simulator in an obvious display of mockery. The spacecraft constructed by contractor North American Aviation had actually been delivered to Cape Canaveral on 26 August 1966, with 113 major engineering changes due for completion after arrival. Another 623 necessary engineering modifications were identified and completed following delivery.

At 1pm on 27 January 1967, the crew entered the command module and took positions in the capsule atop the Saturn 1B rocket, which was not fuelled for the test. The test itself was not considered hazardous.

Immediately, Grissom noticed an odour he described as similar to "sour buttermilk" in the air circulating through his pressure suit. An investigation caused a delay of an hour and 12 minutes. The issue was later determined to be unrelated to the fatal fire. Meanwhile, communications problems due to a continuously live microphone that could not be turned off caused additional delays. At approximately 6:30pm, Grissom remarked, "How are we going to get to the Moon if we can't talk between three buildings?" Another crewmember noted, "They can't hear a word you're saying!" Grissom repeated the comment as his dissatisfaction increased.

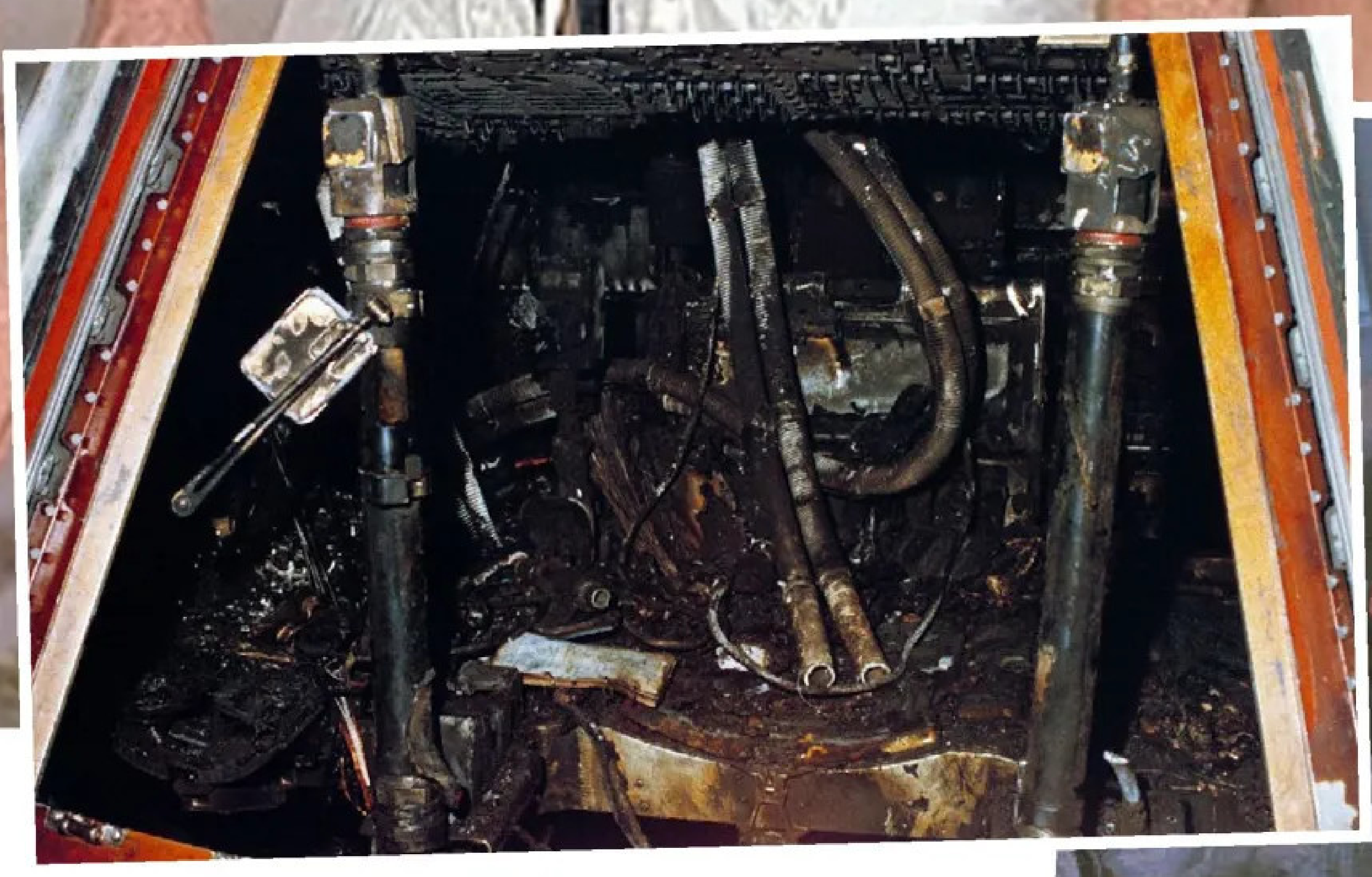


The command module for the ill-fated mission arrives at Kennedy Space Center in August 1966

One minute later, a surge in the spacecraft's AC Bus 2 voltage (alternating current voltage) readings occurred, probably indicating a short circuit in a bundle of wiring. Moments later, one of the crewmen, probably Chaffee, said something like "Flames!" Within two seconds, White said, "We've got fire in the cockpit." Witnesses viewing the closed circuit television feed of the hatch window reported that the flames, accelerated by the 100 per cent oxygen atmosphere and combustible materials, spread swiftly from left to right.

Nearly seven seconds passed before the final communication from the command module was heard. It was probably White who cried out, in a garbled transmission, something to the effect

**Grissom, White and Chaffee in front of the launch pad where, sadly, all three would perish**



“It isn't that we don't trust you, Joe, but this time we've decided to go over your head”

of “We’ve got a bad fire! Let’s get out! We’re burning up!” Seventeen seconds elapsed from the first indication of fire to the interruption of communications. By this time the command module hull had ruptured.

Emergency procedures called for White to open the hatch; however, interior pressure that was higher than external atmospheric pressure made this impossible. Opening it from outside required the use of ratchets and could be accomplished in about 90 seconds in normal circumstances, but thick, black smoke and flames billowed throughout the immediate area, preventing ground personnel from completing the task for five minutes.

The Apollo program was suspended as a NASA review board examined the evidence available and concluded that six conditions had contributed to the disaster: a sealed cabin pressurised with an oxygen atmosphere; an extensive distribution of combustible materials in the cabin; vulnerable wiring carrying spacecraft power; vulnerable plumbing carrying a combustible corrosive coolant; inadequate provisions for the crew to escape; and inadequate provisions for rescue or medical assistance. NASA engineers, North American Aviation, and others had failed to give adequate attention to aspects of the program they considered “routine”. They had evaluated the possibility of catastrophic fire in space but never fully contemplated such an event while the spacecraft was still on the ground. The US Senate and House of Representatives each conducted inquiries into the disaster as well.

As a result of the awful ultimate sacrifice made by the three astronauts, numerous design modifications were completed in subsequent Apollo spacecraft. Lessons had been learned at a great cost. AS-204 was renamed Apollo 1 in honour of the crew, and their bravery is recalled annually during a Day of Remembrance. An exhibit honouring Grissom, White, and Chaffee opened at the Kennedy Space Center in 2017.

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# Apollo's first crewed flight

Astronaut Walt Cunningham, who piloted the first successful crewed mission in the Apollo programme, explains the dangers he faced when making his way into space

**Interviewed by Gemma Lavender**

**BIOGRAPHY**

**Walt Cunningham**

Walt Cunningham was the Lunar Module pilot on the Apollo 7 mission. Before his career with NASA, Cunningham was a fighter pilot with the US Marine Corps and successfully gained a doctorate in physics. After his flight into space with Walter Schirra Jr and Donn Eisele, Cunningham worked in a management role for the space station Skylab.

**Could you tell us why you became an astronaut?**
I can tell you, it wasn't for the money. My starting salary when I went to work for NASA was $13,050 a year. When I left eight years later, I had worked my way up to $25,000. I did sit down once and calculate that if I got paid 50 cent a mile, I would have made $2.24 million.

I should mention that we weren't covered by NASA's flight insurance. If we had been, the payment would have been too high for the other employees of NASA. But overall, let me tell you, it was one of the world's greatest jobs. The Sixties through to the Seventies was the golden age of manned space flight. It was very much like the Twenties, which saw the development of aeroplanes. We weren't flying planes with silk scarves but, you know, we felt like it.

**Did you always want to be an astronaut? What does it take to become an astronaut?**
Well, in 1963 I was a US Marine Corps fighter pilot, working on a doctorate in physics at the University of California, Los Angeles (UCLA). When I applied to NASA to become an astronaut, it turned out I was one of 770 qualified applicants and one of the eventual 14 that would later go into space.

Well, some good people didn't make it. I will never forget we were down to 34 people when we showed up for our eight-day physical. I thought that my friend, a Navy lieutenant who went by the name of Bob Shoemaker, was a sure thing in being selected.

Well, when we left after eight days, I went home and Bob went home. But Bob was out of the running to become an astronaut – he had been diagnosed with bone tuberculosis. It took him six months to get his wings back and he was then transferred to Vietnam. The next time I saw him, it was in a picture and he was being led through a Vietnamese village with his arms tied behind his back. Bob was shot down in Vietnam.

So who does make it? I think we were all bright, healthy, in good physical condition, motivated and self-starters, with a feeling of strong self-confidence. We knew where we were going and how we were going to get there. I think a lot of people would call that ego [laughs]. At the time, spaceflight was considered too tough for anyone that was over 30. It was thought that a younger fighter pilot could endure the wear and tear of space travel. It was a young man's game. Or so we thought.

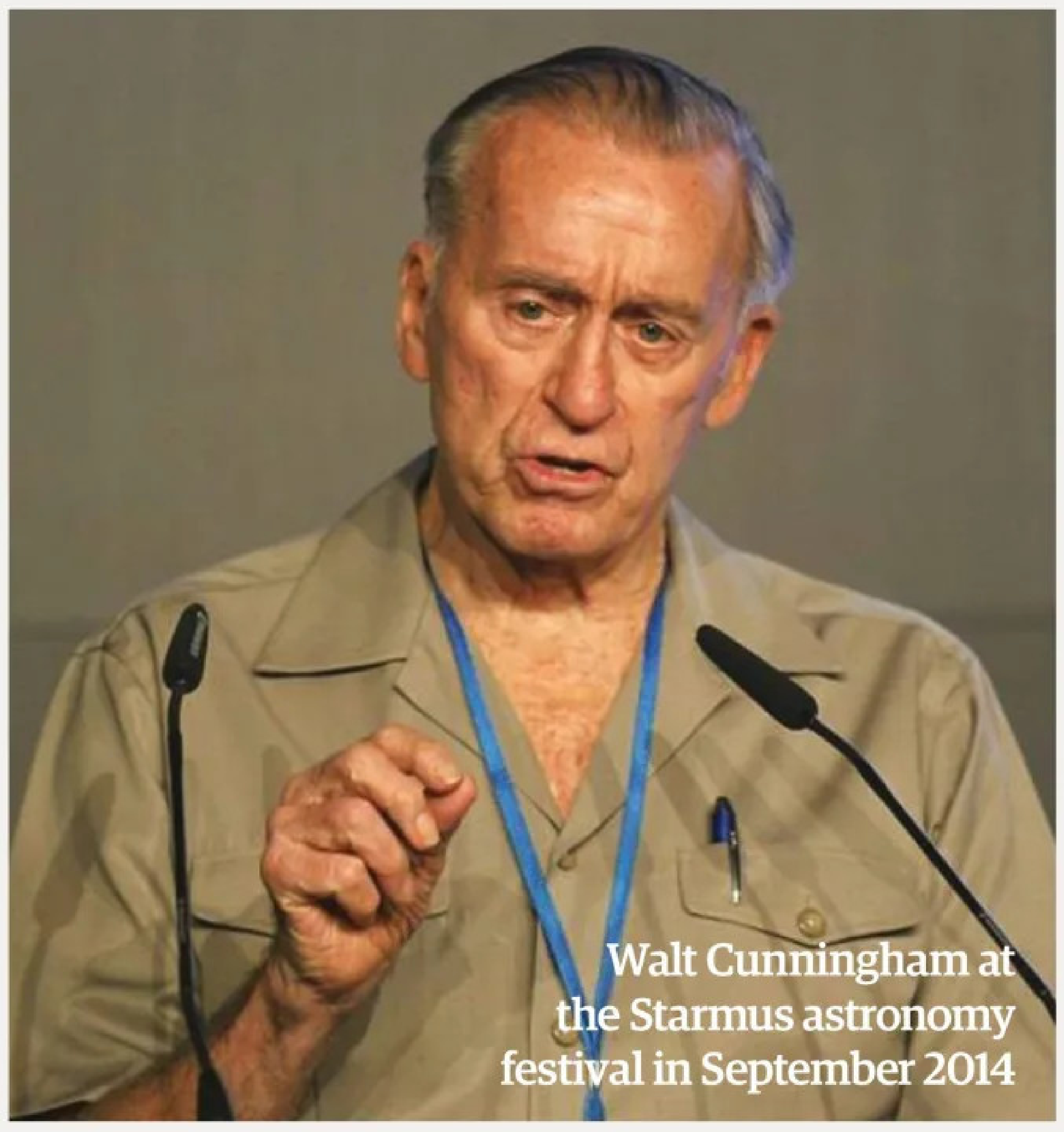
Today, the average age in astronaut office is 45 years of age. Back in those good old days we were hired based on experience and qualifications. I had military training and so had spent much of my life facing risk. In essence, we didn't shy away from the unknown and we were willing to take a risk. Surviving a very dangerous profession, where we were well aware of where we were going and how we would get there. And, we depended on each other with our lives.

**The first Apollo mission ended in disaster with its astronauts being killed in a cabin fire. Were you afraid that something similar would happen?**
Three men [Gus Grissom, Edward White and Roger Chaffee] paid the price of progress and I lost three good

Cunningham says that the next chance for dangerous adventure is the exploration of Mars

Cunningham was one of 14 astronauts selected by NASA in 1963 friends in that fire. But was I afraid of the mission? No. The only thing I can recall having was a fear of failure. Each of our team had the same thought: "If this mission fails, it won't fail because of me". We weren't afraid of accepting the challenge – we had already accepted that. We were afraid to be found lagging behind our peers.

Apollo 7 was really the first step in a plan to land man on the Moon. That plan had five giant steps. Apollo 7 was built for test and operations, systems and spacecraft, then Apollo 8 had to overcome the psychological barrier of leaving the Earth's gravitational field and heading to the Moon. Apollo 9 had to overcome another barrier in testing the Lunar Module in Earth orbit, so its astronauts [James McDivitt, David Scott and Rusty Schweickart] spent a lot of time in the Lunar Module separated from the Command/Service Module. Apollo 10 was a complete dress rehearsal of landing on the Moon.


Walt Cunningham at the Starmus astronomy festival in September 2014

**Did the Apollo 1 disaster set the programme back a considerable amount?**

Absolutely. The Apollo programme schedule slipped and it was eventually cancelled. We also used a different model of space capsule from that time on. It took 21 months to recover and make all of the changes necessary that we thought could have caused that fire. There were a lot of operational changes on the spacecraft in the meantime.

So Apollo 7 was considered – at the time – to be a very ambitious effort to make up for lost time. It was planned for 11 days to test all of the propulsion and all of the spacecraft systems, all of the docking, all of the rendezvous manoeuvres, ground systems… you name it, it was tested. To this day, Apollo 7 is one of the most ambitious and most successful test flights of one of the first new flying machines ever. That spacecraft was near perfect. It was a wonderful accomplishment.

**What reception did you get when you returned ?**

As astronauts, we were at the tip of the spear and we got the glory. The success of our Apollo programme, though, was really down to the collective effort of 400,000 members of our team of the US government and private industry. Against enormous odds, with the whole world watching, a group of engineers, scientists and managers accepted a challenge and took the risk and that team changed the way that we perceive our world. I'm proud to have played a small role in a historical accomplishment.

**What are your memories of Apollo 11? What did it feel like to know that you were part of a programme that landed on the Moon?**

When Apollo 11 touched down with only 17 seconds of fuel, we all started breathing again. It really was something – and, of course, Neil Armstrong's footprint on the lunar surface has gone down in history. When I mention the Apollo programme, everyone thinks of 'one small step for man, one giant leap for mankind'. That's certainly one mission for the history books.

There are other things that I remember from that time, too. For example, you might not know that Apollo 11 carried tubes of microfilm with it with messages from many nations of the world. Some time after the mission, I got the chance to review those messages. One of them, which was praise from the Australian Prime Minister, I carried around in my pocket with me for years. He said: "The chance of dangerous adventure is available to all." What a wonderful statement. The chance of dangerous adventure means accepting the risk of failure. If you're not willing to risk failure, you don't deserve to win. But when you do win, you win big. I believe that is true in all fields of human endeavour.

Apollo 11 is a technological achievement, built by men that think and work like machines. But I don't think we were computers or robots. We were warm, feeling, committed individuals. For a time, after landing on the Moon, we felt together and confident in our abilities to do anything we set our minds to. It was an accomplishment that expanded the envelope of human experience.

> "In the next century they won't care how carefully and cautiously you survived the 21st Century"

UNITED
STATES
Cunningham, along with fellow Apollo 7 astronauts Walter Schirra and Donn Eisele, participates in water egress training in the Gulf of Mexico

**You mention that NASA took quite a few risks with the Apollo programme, is that still true of the agency today when it comes to spaceflight?**
Today NASA has evolved into a less-efficient agency. Management today seems intent on eliminating risk and looking for absolute assurance that something could actually be done before committing to do it. Actually I believe that the American space programme is more of a reflection on today's risk-averse society. That once rambunctious spirit of innovation and adventure is being paralysed by the desire for a risk-free society. Well, I tell you this, exploration is not about eliminating risk. It's about managing risk. We're overwhelmed today with politically correct decision making. The only real limits, other than funding these endeavours, are the risks that we place on ourselves. I don't think we should be worrying about what is politically correct; we have to do what's right – even if it's unpopular.

NASA has been sliding down this hill for some time and this new attitude may have opened the door for so-called commercial space companies. NASA has always depended on private industry and most of today's commercial space companies are really government subsidised. Today, however, NASA will have far less control over the development, operations and the outcome of what's going on in private space companies. Commercial space companies explore space by the return of investment and profit margins and, believe me, the exploration of space does not satisfy either of those criteria. The financial return really comes from the commercial spinoffs, utilising the technology that was developed to make exploration possible. That's why we have many of the things that we're enjoying today because of what went on with the Apollo programme. I think it's going to be that way for the foreseeable future anyway. Safety can never be guaranteed when we explore the unknown to venture out into the unexplored frontiers, it has always been necessary that explorers should be willing to die for their efforts.

**What qualities should an astronaut have?**
It takes those willing to accept the challenge and who are prepared to pay the price. When we look back at the Apollo programme, we can see that it had it all: competition, challenge, imagination, leadership, teamwork, and technological breakthroughs. It also had its risk and uncertainty, its chance of dangerous adventure and it wasn't just the risk of dying – men did die in their heroic efforts. The Apollo programme advanced man's knowledge in dozens of fields of endeavour. Each mission was uncertain until splashdown. So they certainly measured up to the criteria of adventure.

**What do you think is man's next greatest adventure when it comes to space exploration?**
For today's generation, the chance for dangerous adventure is the exploration of Mars. We have the resources, and the technology can be developed, but it's up to them to have the will to tackle this next frontier. Believe me, in the next century they won't care how carefully and cautiously you might have survived the 21st Century but they will celebrate your willingness to expand our universe and to change the way that we look at another world.

Cunningham and his crew mates were launched from Cape Canaveral, Florida, in 1968

Apollo 7 was the first manned Apollo space mission. Cunningham (right) is pictured with Command Module pilot Donn Eisele (left) and Commander Walter Schirra (middle)

© NASA

# A trip around the Moon

The Apollo 8 mission achieved a number of significant firsts for NASA and set the stage for later lunar operations

Apollo 8, the second successful manned mission of NASA's Apollo program, was originally intended as a test flight for the lunar and command/service modules that would later take American astronauts into orbit around the Moon and to the lunar surface.

However, an abrupt change in plans brought Apollo 8 to even greater significance as the crew achieved a considerable number of firsts for NASA, the Apollo program, and for mankind. Ironically, the elevated status of Apollo 8 resulted from a nudge by the rival space program of the Soviet Union. In September 1968, its Zond 5 spacecraft had carried animals into a loop around the Moon and returned safely. Rumours circulated that the Soviets intended to launch a similar manned mission before the end of the year.

Originally scheduled for early 1969, Apollo 8, the first manned space flight to originate from Florida's Kennedy Space Center, launched on 21 December 1968, following modifications to the mission. Although Apollo 8 initially included a lunar orbital flight of the command/service module and lunar module, a riskier command/service module only alteration was approved because defects in the lunar module required more time to correct, possibly jeopardising the goal of putting a man on the Moon before year-end 1969. Moving the Apollo 8 timetable forward would allow the testing of critical lunar landing procedures that would otherwise have been delayed.

Apollo 8 launched at 7:50am. Two hours and 50 minutes later the crew received clearance for translunar injection, firing engines to point the spacecraft's trajectory toward the Moon. Just over 68 hours after liftoff, Apollo 8 reached an elliptical lunar orbit.

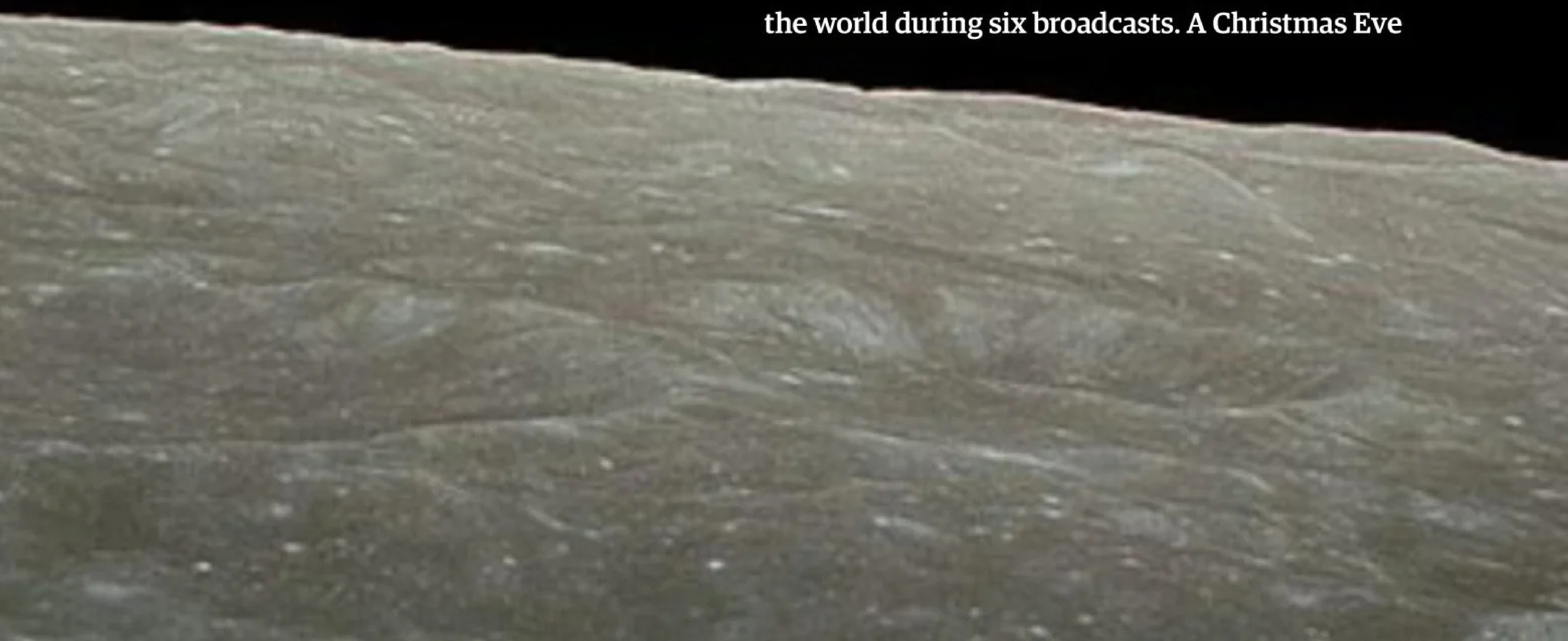
During their seven-day mission, the crew , consisting of Air Force Colonel Frank Borman, commander; Navy Captain James Lovell Jr, command module pilot; and Air Force Major William Anders, lunar module pilot, made history. Borman had previously set a space endurance record during the 14-day flight of Gemini 7 and served on the NASA review board investigating the fire that claimed the lives of the three Apollo 1 astronauts, while Lovell had flown with Borman on the record-setting Gemini 7 and commanded Gemini 12. Apollo 8 was Anders' first and only space flight.

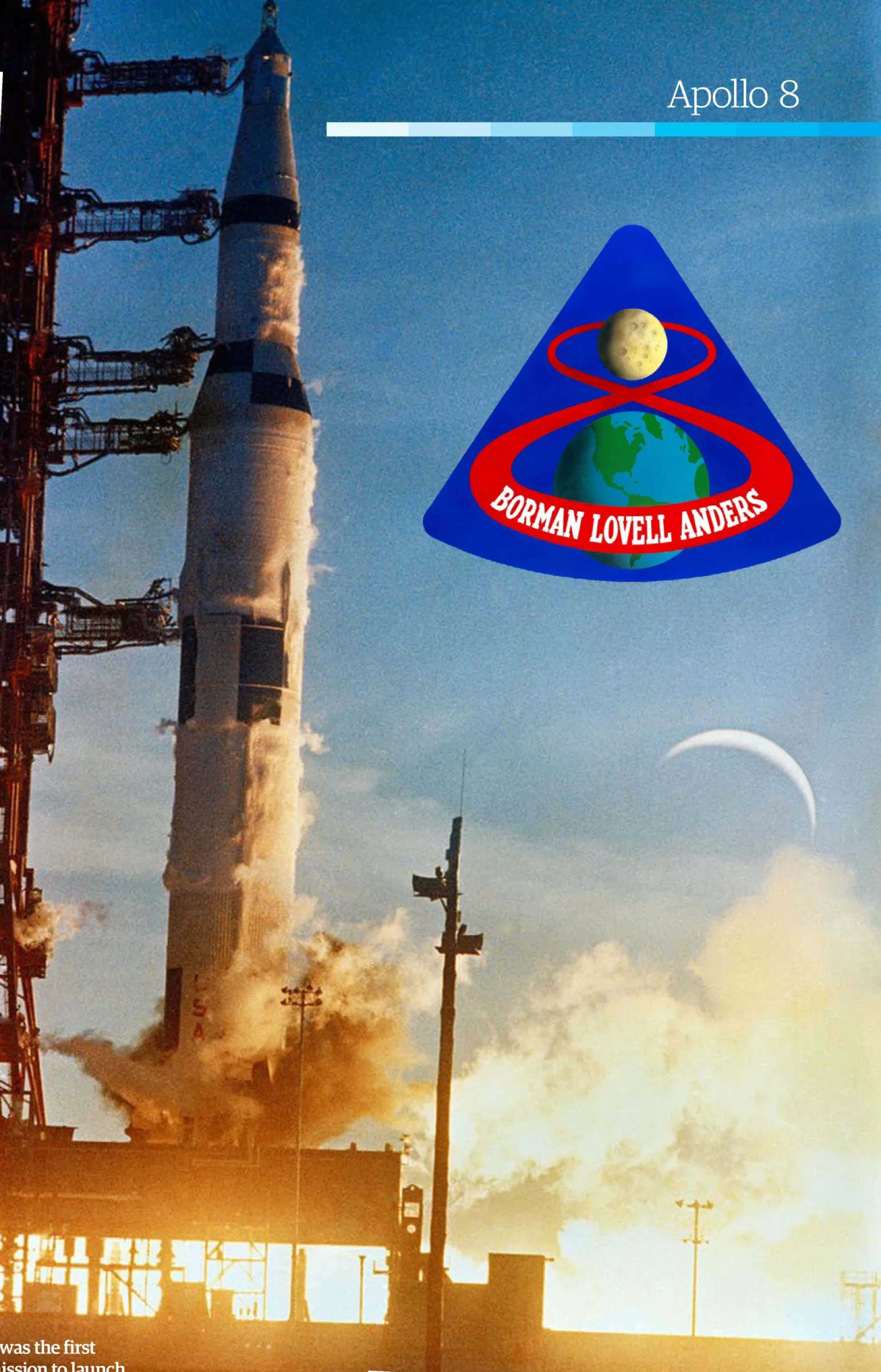
The Apollo 8 crew was first to leave Earth's orbit, then orbit the Moon, returning safely. The three astronauts were the first to travel beyond a low orbit of Earth, to see Earth as a whole planet, and to directly view the dark side of the Moon. They were the first humans to escape the gravitational well of another celestial body, the Moon, and to re-enter that of Earth. Apollo 8 orbited the Moon ten times, but placing the spacecraft in its proper position was quite an achievement. The necessary engine burn had to occur at a precise time, on the dark side of the Moon, out of contact with Earth, and despite the tension this caused, it was successful.

On 24 December, the astronauts witnessed the breathtaking Earthrise above the Moon's horizon. The moment was exhilarating and somewhat unexpected. Anders seized the opportunity to snap one of the most iconic photographs of all time, and the haunting image became a symbol of environmental awareness.

During their historic Christmas flight, the Apollo 8 crew was visible to television viewers around the world during six broadcasts. A Christmas Eve

The first image of the whole Earth was taken by the astronauts aboard the Apollo 8 mission





Apollo 8 was the first Apollo mission to launch aboard a Saturn V rocket, the kind that later took Apollo 11 to the Moon

orbiting the Moon was like a "vast, lonely, forbidding expanse of nothing." Lovell mentioned the planet Earth's "grand ovation to the vastness of space." The crew read the first ten verses of the Book of Genesis from the Bible before signing off, "Good night, good luck, a Merry Christmas and God bless all of you – all you on the good Earth."

On Christmas Day, the required battery of lunar landing tests complete, Apollo 8 began its homeward trek. 'Trans-Earth Injection' had to occur at the right moment on the far side of the Moon. The procedure was executed to perfection, and when communications were restored Lovell pronounced, "Please be informed, there is a Santa Claus!" At 10:51am Eastern Standard Time on 27 December, Apollo 8 splashed down in the Pacific Ocean. By 12:20pm, the astronauts were safely aboard the aircraft carrier USS Yorktown.

The Apollo 8 mission was a resounding triumph. Yet, there had been tense moments before and during the historic flight. The Saturn V rocket had exhibited serious problems during the earlier unmanned Apollo 6 mission in the spring of 1967, including pogo oscillation – a vibration in the liquid propellant filled rocket engines caused by the instability of combustion – along with two second-stage engine failures, and a third stage that did not ignite while orbiting Earth. A manned flight was too hazardous unless these issues were corrected. Satisfactory modifications were installed and testing completed just three days before the scheduled launch. However, eighteen hours into the mission, Borman became ill with vomiting and diarrhoea. He slept for a while and declared that he felt better, but protocol required notifying mission control of the situation. To avoid breaking the news to the public, a private communication channel was used. Several hours later, after consultation with flight surgeon Chuck Berry, senior NASA officials allowed the mission to continue rather than aborting.

During the return flight, Lovell accidentally erased some computer memory while working on navigational sightings. When the crew discovered that a misalignment had occurred due to an unintentional thruster firing based on earlier data, it became necessary to manually calculate and enter the correct information. Within 25 minutes, Lovell had determined the appropriate data and performed the computer input, averting a disaster.

Sixteen months later Lovell was in command of the Apollo 13 lunar landing mission, which aborted due to an on-board explosion. He recalled that his computer-related experience aboard Apollo 8 was useful in bringing the later crew home.

The three Apollo 8 astronauts were named *Time* Magazine's Men of the Year for 1968, proof that their mission captured the public imagination.

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**BIOGRAPHY**

**Russell Schweickart**

Rusty Schweickart served as the Lunar Module Pilot on Apollo 9, where he performed the first in-space test of the Portable Life Support System, used by Apollo 11's Neil Armstrong and Buzz Aldrin on the Moon. As well as developing the hardware and procedures used by the crew on the first Skylab mission, he was awarded the NASA Distinguished Service Medal, the National Academy of Television Arts and Sciences Special Trustees Award (Emmy Award) and the NASA Exceptional Service Medal.

“On my EVA, I remember being way up the front of the Lunar Module with my hand on the handrail, and I just let go”

# *Apollo 9's* Rusty Schweickart

## The retired NASA astronaut explains how a jammed camera during a spacewalk changed his life forever

**Interviewed by Rafael Maceira Garcia**

**If NASA had stuck with its original rosters, the crew of Apollo 9 should have flown on Apollo 8, circling the Moon during Christmas 1968. How did you take the news that you were not going to fly to the Moon after so much hard training?**

Well… Those were very complicated times and the mission shifted all over. We were actually the back-up crew for the first Apollo missions including Apollo 7, but we were also going to pick up the Lunar Module and be the first to fly it. Then we were shifted off the back-up crew and Wally Schirra's team took our places for the first Apollo mission, with Gus Grissom, Roger Chaffee and Ed White the appointed first choice crew. We moved into a totally different mission, but we were going to fly the Lunar Module. Then that didn't work and Frank Borman proposed moving his flight.

**Did you ever have the feeling of having lost the chance of going to the Moon?**

No, not then, but after we flew on Apollo 9 and tested the Lunar Module in Earth orbit, the next rotation would have been to go from Apollo 9 to being back-up for Apollo 12 and then a member of the prime crew on Apollo 15, which Dave Scott did. But things changed because I had gotten sick on Apollo 9. I had motion sickness, and as the first person, not to get sick, but the first person to acknowledge it [laughs] - that's an important difference - there was a big question as to whether people getting sick might actually make going to the Moon unsafe and dangerous for people. So we had to learn something about that and I volunteered to be the guinea pig to test motion sickness, so that we came to understand what was going on there and how we could overcome it, etc… So that took me out of the normal rotation. That's the way that happened.

**You lifted off as the pilot of the Lunar Module with the first complete Apollo spacecraft on 3 March 1969. What moments or lessons would you point out from that experience?**

Well, I mean, the primary lesson from our experience on Apollo 9 was that everything worked well. We'd had a lot of problems in Gemini doing EVA with a suit and they were largely unsuccessful, but we had the brand new suit. I had to go on the EVA, the first experience of going outside, and fortunately, nothing really dangerous happened. We also had the backpack that was going to allow us to run around on the Moon. So that was a very important test that we did in Apollo 9.

**Did you have to deal with the motion sickness too?**

Yes, but that was over by the time we actually did the EVA. We had to postpone the EVA because I had motion sickness the day before, and you don't get in a suit and go outside in space if you're going to have motion sickness, because that will kill you. I mean, if you vomit in the suit you will die. It's very dangerous.

**You have the honour of being the astronaut that performed the first Apollo spacewalk, testing the new spacesuit's integral life support systems. How do you recall your feelings before and during such a historic time?**

Going outside is always a special time for any astronaut, no matter how you do it. Whether you're the tenth or the thousand person, going outside the spacecraft is always a very special experience because you're really out there, you're no longer looking through a window. Even if you looked around in your Apollo suit you didn't see the edge of anything, so it's as if you're naked in space. And if you're not moving around you don't feel the suit, as you're floating inside it. So the feeling is very much of just being out there all by yourself. You're a *2001* baby in space. So it's always a special time. Then, of course, on Apollo 9, I recognised that we'd had problems before in the suit, and we didn't know what to expect from the new Apollo suit. We also never flew with a totally self-contained backpack, I only had a tether to the spacecraft. There was no umbilical chord, so in other words, I had no services coming through that tether. So everything was on my

Inside the Apollo Lunar Module mission simulator at the Kennedy Space Center, Florida, during Apollo 9 mission training

“I was an independent spacecraft really, linked by a string to the Apollo craft, and it all worked beautifully”

Russell ‘Rusty’ Schweickart was selected in 1963 for NASA’s third astronaut group

NASA astronaut Schweickart flew on the first manned Earth orbital test flight of the Apollo Lunar Module

The Apollo programme was debatably the most successful human spaceflight programme carried out by NASA

back and in the suit. I was an independent spacecraft really, linked by a string, and it all worked beautifully.

**As a fighter pilot and an astronaut you're trained to handle risk - were there any risky moments?**
We really didn’t have any risky moments. Everything worked well. There were a couple of surprises when we first undocked the two spacecraft. It gets a little bit technical, but there were some very small little latches that had to release, and in the simulator on the ground, when we did the procedure everything worked well. Dave Scott in the Command Module threw the switch and the two spacecraft separated. Springs pushed us apart and the spacecraft moved away, but when Dave pushed the switch and let it go in the actual situation, the probe had not fully extended. He just hit the switch and let it go - which is what we did in the simulator on the ground - but when it reached the end of its travel pushing the Lunar Module away, those little latches (as soon as he let go) went back out and so we went ‘clunk’, and stopped. We kind of looked at each other and wondered, “What was that?” McDivitt and I said we should probably redock and figure out what happened. We wanted to let the ground team work through it and figure out what happened, and then do it again. At about that time, Dave looked up and saw that we weren’t separated and he just hit the switch again. As we started to drift off, we looked at each other and said: “Well, too late now! So we'll find out when we come back from the rendezvous in eight hours if anything is wrong.”

**What do you treasure most from your mission?**
The EVA. Being outside the spacecraft and having five minutes to myself when the movie camera that was documenting my EVA failed. Jim McDivitt said: “Okay Dave, you’ve got five minutes to try and fix the movie camera. Rusty, just stay there.” Well, that was great! I mean, I had five minutes to just stay there and look at where I was. So that was pretty special.

**Did the mission change you in any way?**
Well, yeah, because you know, during those five minutes… I remember being way up the front of the Lunar Module with my hand on the handrail, and I just let go. With one hand I swung myself around and looked at the Earth; the Command Module was also in that direction, but mainly I could see the Earth, the black sky and the black universe above it. I just said to myself: “This is my time to be a human, not to be an astronaut. I’m not going to think about what’s next on the checklist. My job is to be a sponge, to just let this come in through the spacesuit and into me as a human being.” And that happened. Many years afterward, I was still processing it. A lot of questions came to me: How did I get here? And I don’t mean by a Saturn V. How do I happen to be here? I was a farm kid from New Jersey. What’s happening? What does this mean? Why am I here? What are the implications of this? What is my responsibility? All of those things just came flooding in and those were things that I processed for several years afterwards, before I really talked about that experience in that sense.

**What do you think is the legacy of Apollo 9?**
The Apollo 9 was the engineering test flight. We

Schweickart performs an EVA standing on the Lunar Module porch, photographed by fellow astronaut James McDivitt from inside

> “Going to Mars is going to be a much bigger challenge, and it’s not clear to me how soon we’re going to be able to do that”

would basically test everything. Everybody said it was the engineer’s flight, because everything that had to work in order to make a successful lunar landing was tested. Well, not everything, because we didn’t test any of the actual landing radar, for example - because we didn’t have the Moon there - but 90 per cent of what had to work we tested on our flight. In some cases we went beyond the normal test to make it extra difficult. So it was a very important flight in terms of proving that we really were ready to go out to the Moon and land.

**As back-up commander of the first manned Skylab mission in 1973, you were responsible for developing the hardware and procedures used by the first crew to perform critical in-flight repairs. Can you recall any near-disasters?**

My job at that time was to prepare all of the EVA procedures, retrieve the film canisters, and we also developed better foot restraints so that people were free to move around. All of that was done for the normal operations on Skylab. That’s why I did all that work. Almost all of it was done in neutral buoyancy in the big water tanks, but the reality is that what all of that led to was when Skylab got off the ground and the thermal shield ripped off and took the solar array with it… I mean, we had a disaster in space. It was a matter of ‘Can we save this mission?’ A lot of the work that I had done underwater and in EVA came to the rescue of Skylab. The experience that I had in doing all of the normal work led to a capability where we literally saved the mission. The things that we designed and tested underwater, as well as the training provided for the crews, were important. It was the Skylab rescue that was the real contribution that came out of the earlier nominal work.

**After Skylab you served as director of User Affairs in NASA’s Office of Applications. Are you still involved in any way with the space programme?**

I’m not directly linked to the space programme in terms of NASA, for example, but the last 15 years of my life have been spent working on what we refer to as planetary defence: protecting the Earth from asteroid impact. That’s what I really am very proud of. I’m as proud of that as I am of having flown on Apollo. Anyone could have flown on Apollo, but that work on the B 612 Foundation and the Association of Space Explorers, both of which I founded, and the work that we’ve done in enabling humanity to protect the Earth, and the life on it, from asteroid impact will be a very important legacy.

**Do you think a trip to Mars is as challenging and risky as the Apollo programme?**

I think there’s no question; it’s far more risky. We know one of the biggest problems in going to Mars is the radiation environment. You are not only going into space for a long time, you’re outside of Earth orbit where you are protected by the radiation belts. That happens when you’re in the Space Station, for example, but when you get out into deep space you are exposed to heavy particles. We don’t really have a good way to protect people from radiation damage. This is a big issue among others; a small group of people going for that long would also experience psychological challenges. The experience of Antarctica, the South Pole, over winter is small compared with a group of people going to Mars for three years. Those things are challenges that we understand, and didn’t exist in going for a week or something to the surface of the Moon with three people. Going to Mars is going to be a much bigger challenge, and it’s not clear to me how soon we’re going to be able to do that. People talk about a one-way trip. Older people like myself, we have lived our lives, so who cares…

**Would you go if you had the chance?**

I don’t think so… Perhaps if my family disowned me, I would think about it, but now I think it’s for younger people to do.

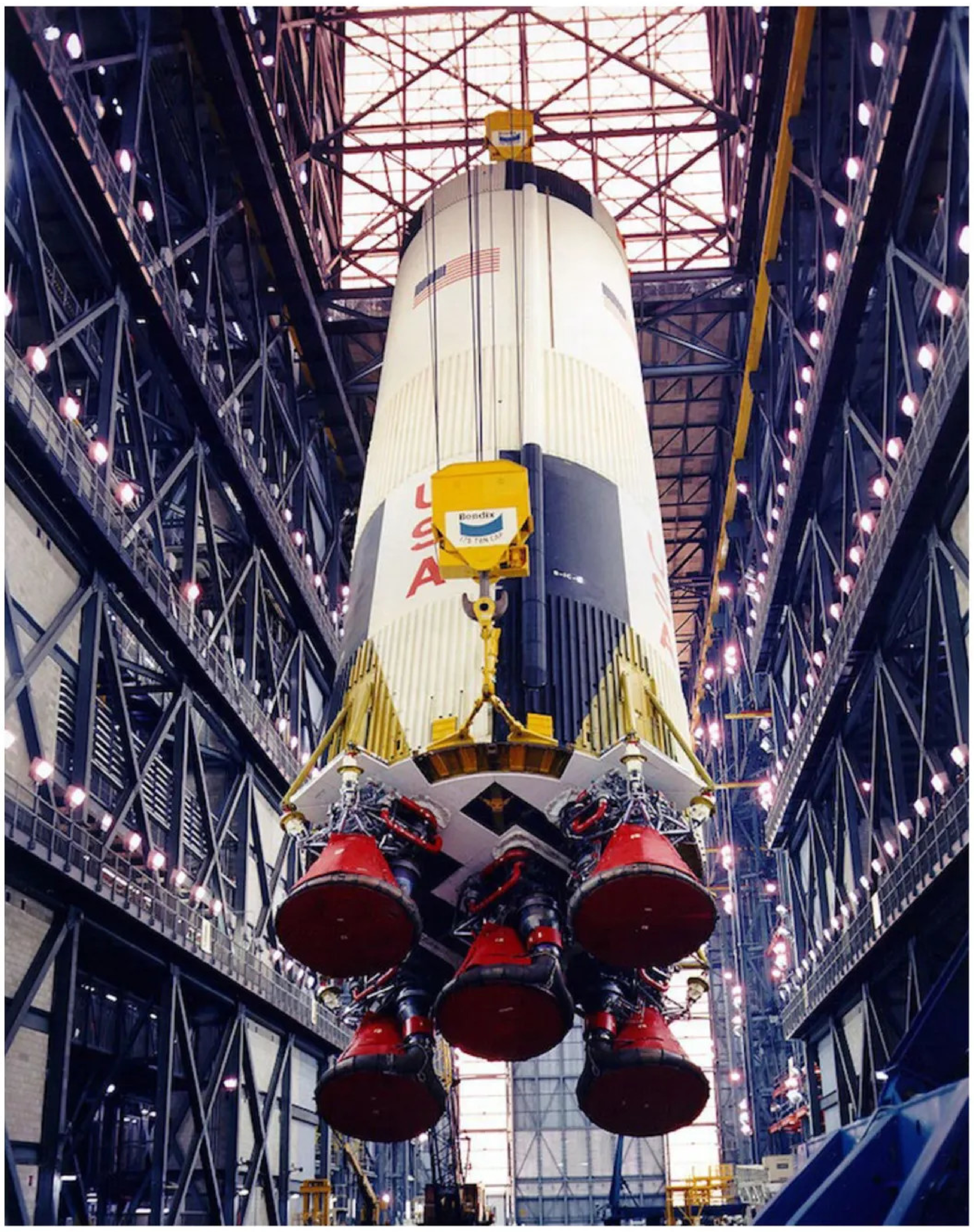
# Dress rehearsal for the Moon

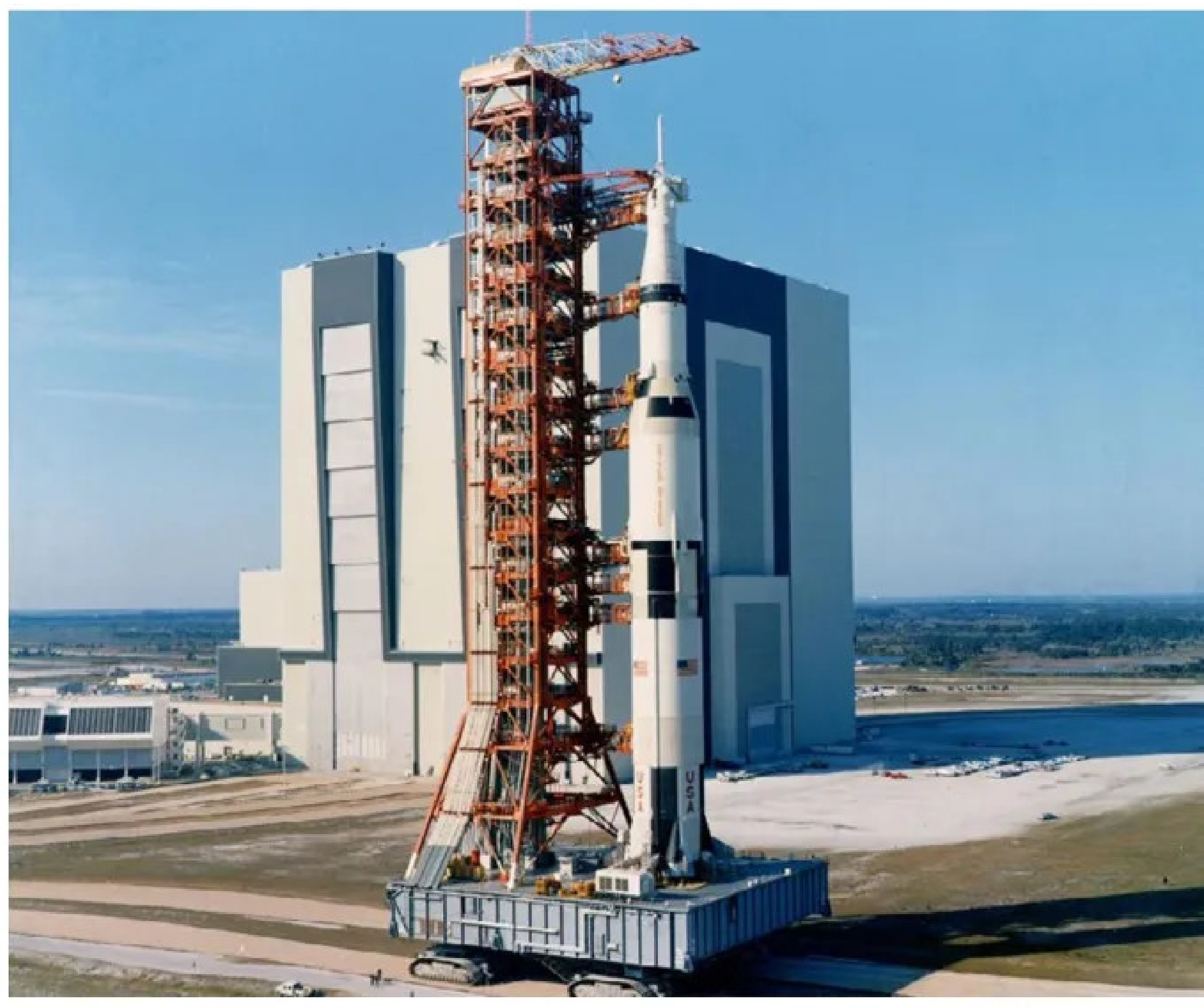
## The crew of Apollo 10 performed every aspect of an actual mission to the lunar surface except the landing itself

The fourth mission of NASA's Apollo program in the short span of seven months, Apollo 10 lifted off from the Kennedy Space Center's Launch Complex 39B on the morning of 18 May 1969. Its objective was clear – to execute every aspect of a lunar landing mission except the actual landing on the Moon.

That defining moment would, hopefully, occur weeks later with Apollo 11. However, unless Apollo 10's dress rehearsal was successful, NASA's goal, placing a man on the Moon before the end of the 1960s, would be in jeopardy.

Apollo 10 was the first lunar mission involving an entire Apollo spacecraft configured for a landing. The command/service module was a two-part vehicle, its cone-shaped command module used as a control station and crew compartment. The cylindrical service module, to the rear of the command module, contained oxygen, hydrogen, fuel, and propulsion and manoeuvre systems. The two-stage lunar module housed a lower descent stage containing the





power plant for the Moon landing. Its construction included four aluminium alloy legs for support on the lunar surface, a ladder for astronaut ingress and egress, and storage space. The descent stage also provided a launch platform for the cylindrical ascent stage, where the crewmen would work while on the Moon's surface prior to lifting off, returning to lunar orbit, and docking with the command/service module.

During the eight-day mission, Apollo 10 set the record for highest speed ever achieved by a manned vehicle at 39,897 kilometres per hour (24,791 miles per hour) while returning to Earth, and achieved the greatest distance humans have ever travelled from home, 408,950 kilometres (220,820 nautical miles) from the crew's houses and NASA mission control in Houston, Texas.

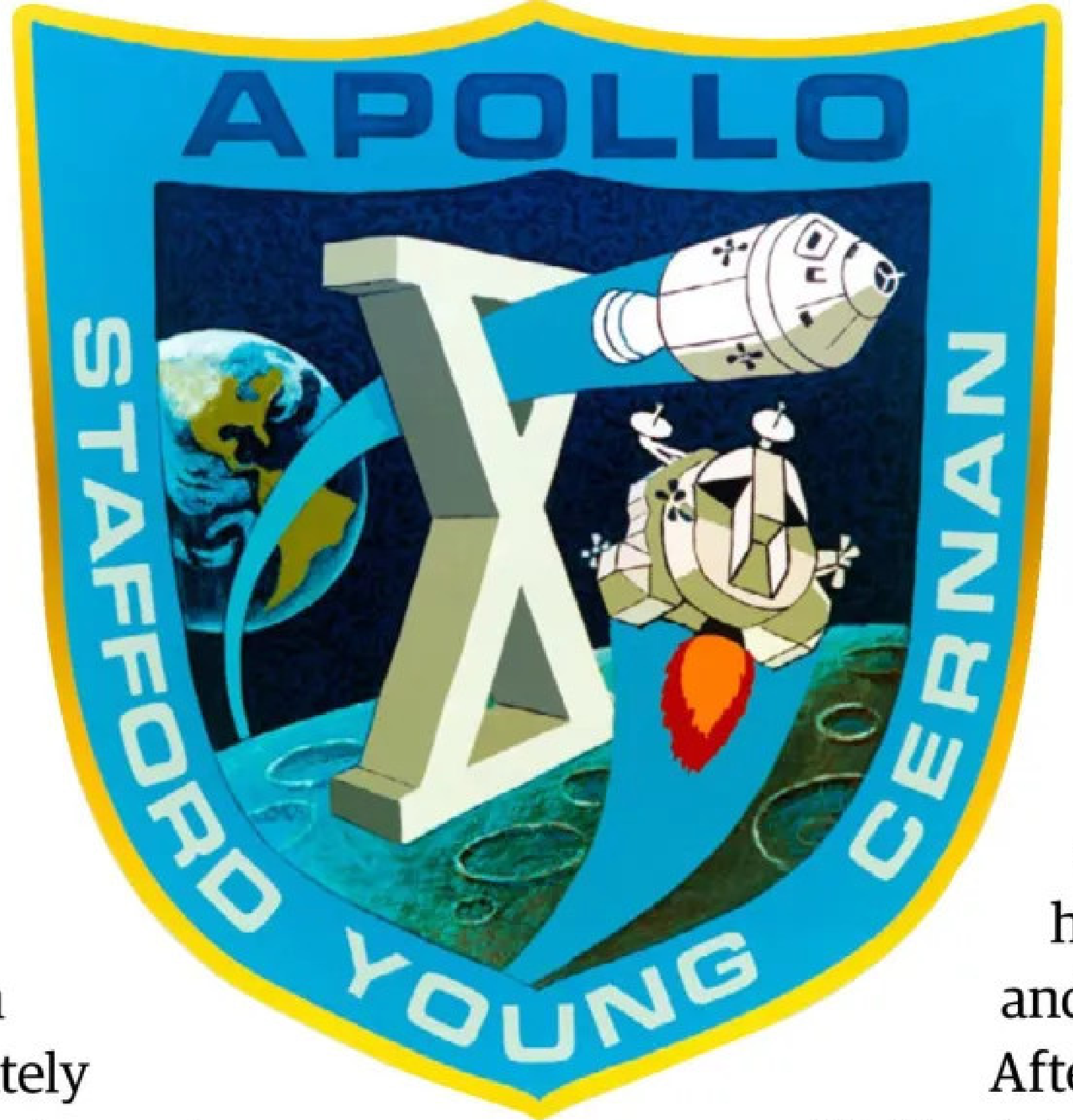
Mission commander Thomas Stafford, an Air Force officer, was a NASA veteran of Gemini 6 and Gemini 9. He was later the mission commander of the Apollo-Soyuz Test Project, a joint venture with the Soviet space program. Lunar Module pilot Eugene Cernan, a Navy officer, flew with Stafford aboard Gemini 9 and later commanded Apollo 17, becoming the eleventh man to walk on the Moon.Command Module pilot John Young, a Navy officer, had flown in Gemini 3 and Gemini 10. He later flew in Apollo 16, becoming the ninth man to walk on the Moon, and commanded two Space Shuttle missions. During Apollo 10, Young became the first person to fly solo around the Moon.

The crew nicknamed its command/service and lunar modules Charlie Brown and Snoopy after popular characters from the *Peanuts* comic strip, and cartoonist Charles Schulz created artwork for the project. The intent was to add a bit of familiarity to the Moonshot, but NASA officials considered the nicknames undignified. Nevertheless, the idea of whimsical names persisted with later Apollo missions.

Twelve television broadcasts were originally planned during the flight, the first to transmit colour images from space. The initial live transmission began three hours after launch, and the cameras provided stunning colour footage of the Earth and the surface of the Moon. By the end of the mission, 19 transmissions totalling nearly six hours had occurred, also offering viewers clear depictions of life aboard the spacecraft.

Once aloft, Apollo 10 completed one and a half revolutions around the Earth before igniting the S-IVB booster stage of its Saturn V rocket, gaining sufficient velocity to escape Earth's gravitational pull. Three days later the spacecraft reached a lunar orbit 111.12 kilometres by 314.84 kilometres (60 by 170 nautical miles) above the lunar surface.

On 22 May, Stafford and Cernan moved into the lunar module, detaching from the command/service module to execute a simulated lunar landing. They proceeded to a temporary orbit of 107.34 kilometres by 115.07 kilometres (66.7 miles by 71.5 miles). The descent engine fired for 27.4 seconds, and the lunar module manoeuvred to an orbit of 15.61 kilometres by 113.45 kilometres (9.7 miles by 70.5 miles). The astronauts then surveyed the proposed lunar landing site in the Sea of Tranquillity while their pre-landing tests were performed.



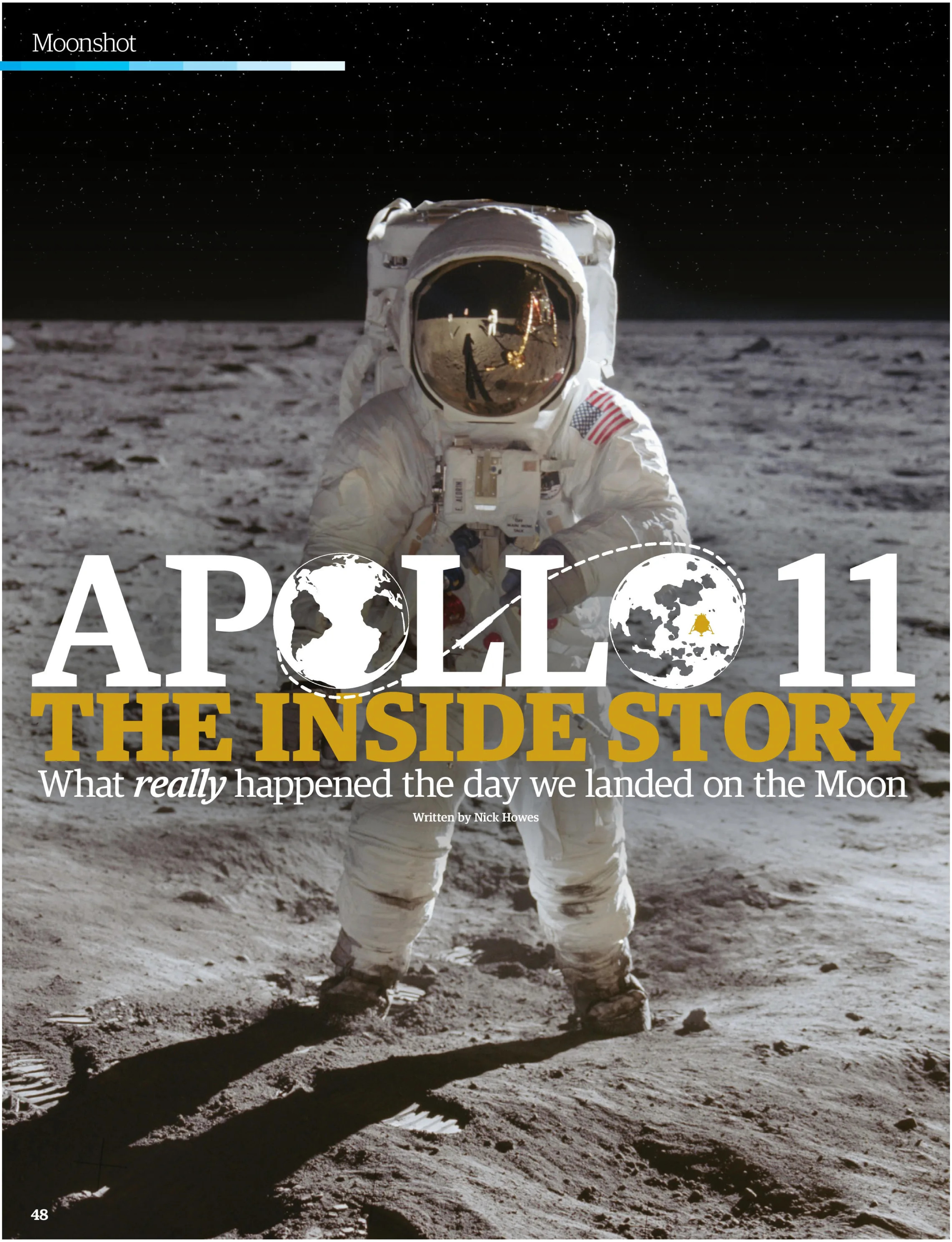
NASA officials had been concerned that Stafford and Cernan might actually go rogue and land the lunar module themselves. Cernan was later quoted as saying, "A lot of people thought about the kind of people we were: 'Don't give those guys an opportunity to land, 'cause they might!'" To eliminate the worry, the tanks in the ascent module were deliberately shorted of fuel. If the Apollo 10 astronauts had landed on the Moon, they could not have returned to the command/service module, where Young was flying alone.

While the command/service and lunar modules were separated, all three astronauts picked up an eerie whistling sound they described as "space music". Young correctly identified the source as radio interference between the two modules, but later disclosure of the event brought implausible speculation among observers that some kind of extraterrestrial communication had taken place.

This portion of the mission narrowly averted disaster when the time came to jettison the descent stage and return to the command/service module. The descent stage separated on the second attempt, and immediately the ascent stage experienced violent rolls. Cernan shouted an expletive that was broadcast worldwide as he struggled to bring the ascent stage under control. He counted eight spirals and managed to pull the vehicle out of the spin with little time to spare before a fatal impact with the lunar surface. Post-flight analysis revealed that a single switch had been in the wrong position and caused the near-catastrophe.

After reaching the proper orbit, Stafford sighted the command/service module at a distance of 77.25 kilometres (48 miles). The vehicles re-docked successfully on 23 May, and the ascent stage was jettisoned. The crew continued routine activities for the remainder of the mission.

The next day, Apollo 10 headed for home. Splashdown in the Pacific Ocean occurred on May 26, about 6.4 kilometres (4 miles) from the recovery ship, the aircraft carrier USS Princeton. The pathway to the Moon was thoroughly charted.



# APOLLO 11
# THE INSIDE STORY

## What *really* happened the day we landed on the Moon

Written by Nick Howes

It's hard for many today to comprehend that over 50 years ago, humankind achieved one of the greatest technical feats of all time. Less than nine years after President Kennedy had set the goal of landing a man on the surface of the Moon and returning him safely to Earth, NASA achieved that most astonishing aim on 20 July 1969.

Those intervening years had been a white-knuckle ride. Beginning with Alan Shepard's 15 minute sub-orbital Mercury flight in 1961, NASA progressed through a series of milestones in their mission to reach the Moon. There was the loss of a Mercury capsule and the near-drowning of its pilot Gus Grissom; John Glenn's re-entry with a retro-rocket still attached to his Friendship 7 capsule; a slew of hugely successful Gemini missions including one that almost span out of control, potentially threatening the life of the astronaut who in 1969 would take that first historic step; and then four fully flown Apollo missions, two in low Earth orbit, two that orbited the Moon and only one to test the full system. NASA had to endure the catastrophic loss of Grissom and his two crew mates, Edward White and Roger Chaffee in 1967 in Apollo 1's tragic fire on the launch pad, but the space agency had resolved to carry on, completely redesigning the lunar command module and carrying out major changes to the lunar landing module (the LEM as it was known) in that short space of time.

Amid triumph and tragedy, on 16 July 1969 NASA was ready to go to the Moon. Yet the trials and tribulations of the previous years were not over and the three-man crew of Apollo 11 – Neil Armstrong, Buzz Aldrin and Michael Collins – were facing one of the most dramatic spaceflights in history.

We recall the historic first words said on the lunar surface, and the elation of the largest TV audience in history at that time when they saw those grainy black and white images from the Moon, but there is so much more to the story of Apollo 11 that may not be as well known.

Their first task, of course, was to leave Earth on top of the mighty Saturn V rocket – the tallest, most powerful rocket ever built. Many astronauts who were propelled into space by the Saturn V describe it as being a very smooth ride. Neil Armstrong is quoted as saying that while the launch for all those watching on Cocoa Beach or at Cape Canaveral was deafening, the crew could detect a slight increase in background noise, a lot of shaking, and feeling akin to being onboard a large jet aeroplane on take-off. Yet as smooth a ride as it was, being on top of that much rocket fuel was always a dangerous experience.

"A space mission will never be routine because you're putting three humans on top of an enormous amount of high explosive," Gene Kranz, flight director for Apollo 11's lunar landing, told us. If there were any nerves, the astronauts weren't feeling it, according to Buzz Aldrin. "We felt that our survival was in the probability of 99 per cent. There were a lot of risks involved but there were a lot of points to abort the mission short of continuing on something risky."

Once in space, the command service module had to rotate and dock with the lunar module, which was

Armstrong waves to well-wishers in the Manned Spacecraft Operations Building as he, Collins and Aldrin prepare to be transported to Launch Complex 39A

This iconic picture shows astronaut Buzz Aldrin's bootprint in the lunar soil

> "A space mission will never be routine… you're putting three humans on top of an enormous amount of high explosive" **Gene Kranz**

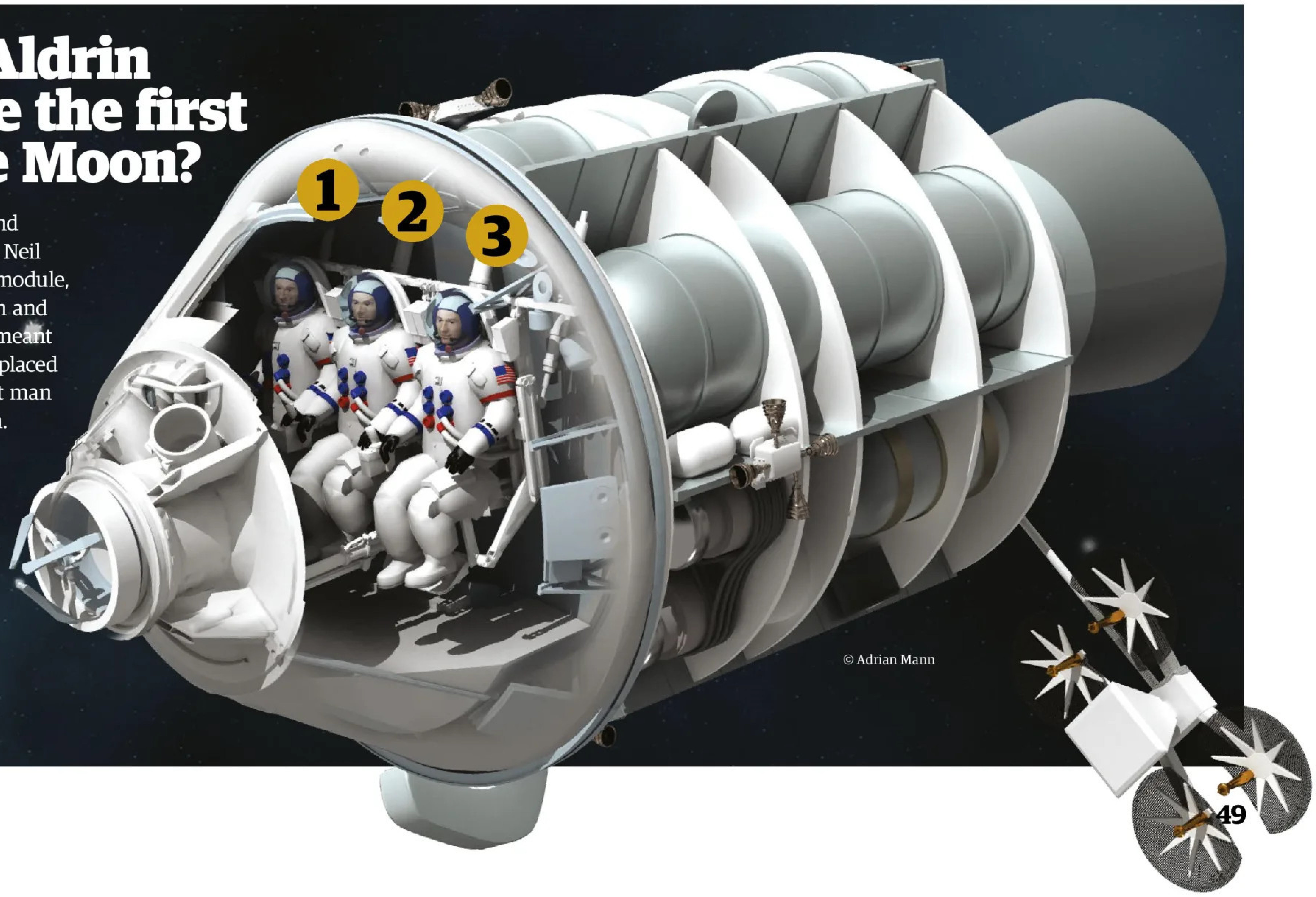
## Was Buzz Aldrin meant to be the first man on the Moon?

The seating plan in the command module. When Buzz Aldrin and Neil Armstrong moved to the lunar module, it's thought that the seating plan and the position of the entry hatch meant that Neil Armstrong was better placed to exit first and become the first man on the Moon, rather than Aldrin.

**1** Michael Collins (Command Module Pilot)

**2** Buzz Aldrin (Lunar Module Pilot)

**3** Neil Armstrong (Commander)



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# BUZZ ALDRIN

## *"Somebody said that [me not taking pictures of Neil] was intentional"*

### After returning to Earth, hardly any shots of the first man on the Moon led Buzz Aldrin to be questioned

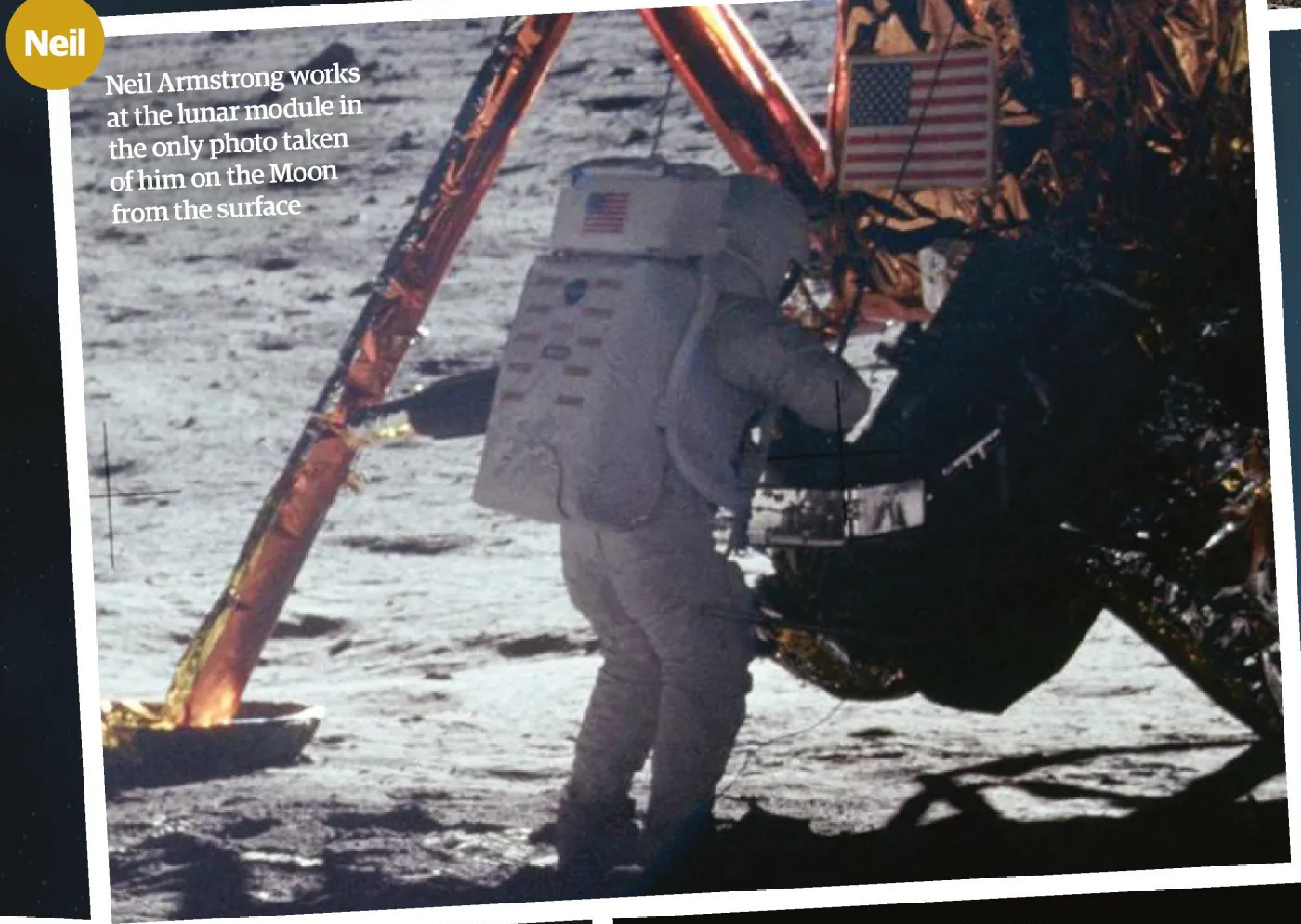
It's said that Aldrin was getting Armstrong back by taking no photos of him on the Moon in retribution for the latter getting the honour of being the first to set foot on the Moon. However, and according to Aldrin, he was about to take a picture of Armstrong at the flag ceremony when President Nixon called, distracting them from the task. "As the sequence of lunar operations evolved, Neil had the camera most of the time, and the majority of the pictures taken on the Moon that include an astronaut are of me," Aldrin states. "It wasn't until we were back on Earth and in the Lunar Receiving Laboratory looking over the pictures that we realised there were few pictures of Neil. My fault perhaps, but we had never simulated this during our training."

Before his death in 2012, Armstrong defended Aldrin, stating: "We didn't spend any time worrying about who took what pictures. It didn't occur to me that it made any difference, as long as they were good... I don't think Buzz had any reason to take my picture, and it never occurred to me that he should."

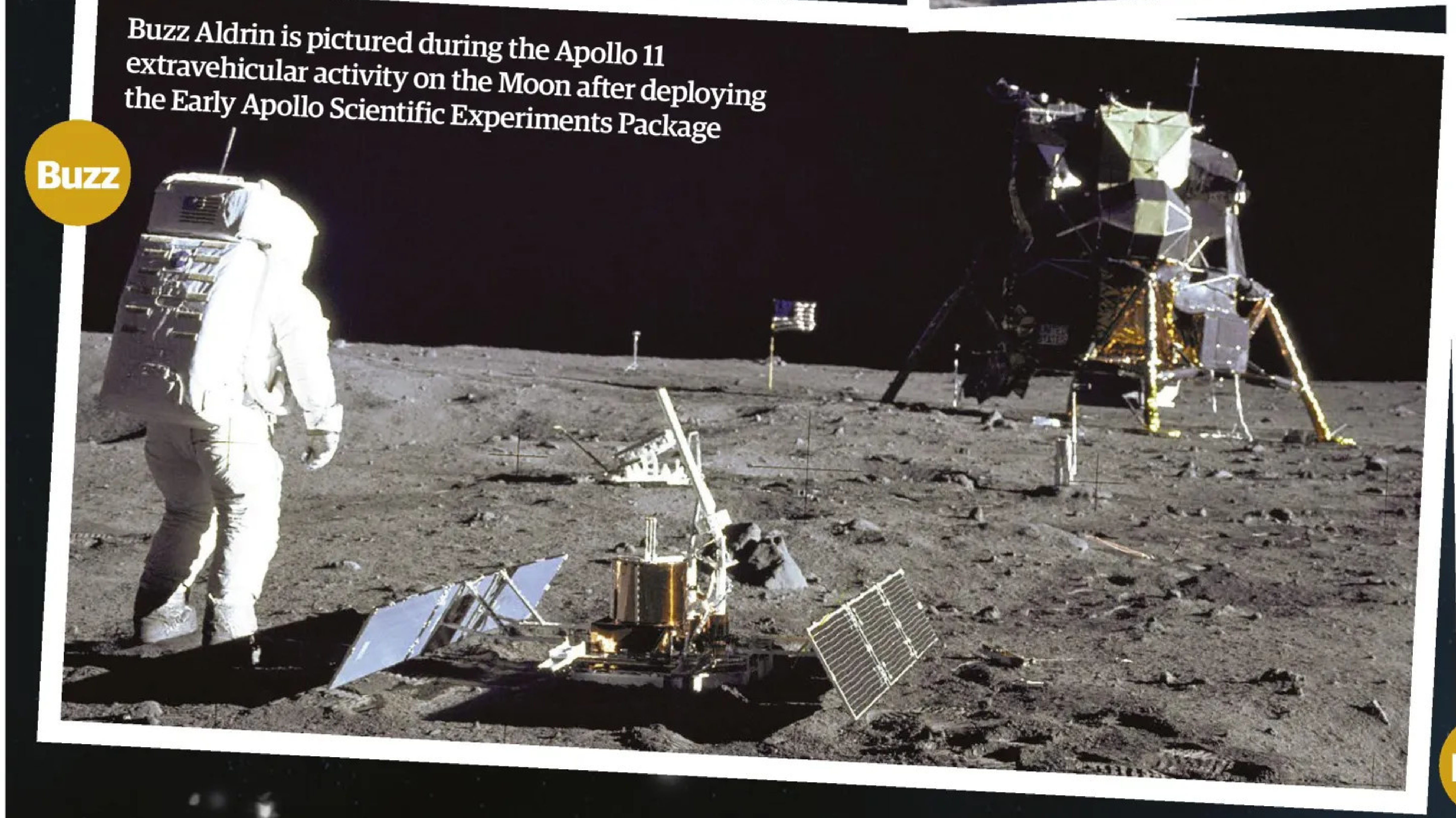
"When I got back and someone said, 'There's not any of Neil,' I thought, 'What in the hell can I do now?' I felt so bad about that," says Aldrin. "And then to have somebody say that might have been intentional... How do you come up with a nonconfrontational argument against that?"

Buzz Aldrin moves toward a position to deploy two components of the Early Apollo Scientific Experiments Package (EASEP) on the surface of the Moon during the Apollo 11 extravehicular activity

The lunar module pilot poses for a photograph beside the deployed United States flag during an Apollo 11 extravehicular activity (EVA) on the lunar surface



Neil Armstrong works at the lunar module in the only photo taken of him on the Moon from the surface



Buzz Aldrin is pictured during the Apollo 11 extravehicular activity on the Moon after deploying the Early Apollo Scientific Experiments Package

Buzz Aldrin walks on the surface of the Moon near the lunar module during the Apollo 11 mission embedded in the final S-IVB stage of the Saturn V rocket. After the two spacecraft had mated, onwards they flew to the Moon, leaving the S-IVB stage trailing in space behind them.

Some time later, the crew spotted something strange outside. A light that appeared to be following them. When Michael Collins used the onboard telescope to view it, he couldn't make it out – it looked like a series of ellipses but, when focusing the telescope, it seemed L-shaped, but that could have just been the way sunlight was glinting off it.

Reticent to tell mission control in Houston, Texas, that they were being raced to the Moon by a UFO, the crew cautiously asked where the S-IVB rocket stage was. "A few moments later they came back to us and said it was around 6,000 miles away," recalled Aldrin. "We really didn't think we were looking at something that far away, so we decided to go to sleep and not talk about it any more."

Aldrin doesn't believe it was an alien spaceship, but that it was more likely the Sun reflecting off one of four metal panels that fell away from the rocket stage when they docked with the lunar module.

For almost four days Apollo 11 flew towards the Moon, where Armstrong and Aldrin climbed into the lunar module – the Eagle – and said goodbye to Collins, who was to remain in the command module in orbit around the Moon.

As the Eagle flew around the far side of the Moon, things in mission control were growing tense. "There was a degree of seriousness in mission control that I hadn't even seen in training," said Kranz. "That was when you realised this was the real deal: today, we land on the Moon."

Almost immediately after separating from the command module there were problems. Radio communication with the Eagle was sketchy at best and they were coming up to the point of no return, where the landing could no longer be aborted if something was wrong.

"It was up to me to decide if we had enough information to make the go/no-go [decision] and continue the descent to the Moon," said Kranz. So, five minutes before the powered descent to the lunar surface was due to begin, with radio communication cutting in and out, Kranz asked his flight controllers to give him their go/no-go based on the last frame of data that they saw. They all said "go." And then things turned from bad to nearly catastrophic.

The spacecraft's guidance computer, developed at MIT under the auspices of Charles Draper (the lab at MIT now bears his name) was a 2MHz system that was the first in the world to use integrated circuits. Its fixed memory was an ingeniously designed 'Core Rope', which consisted of a set of small hoops that 'Little Old Ladies' (as they were referred to at the time) along with machines would thread the code either through or around the hoops to give the computer its 1 or 0 value. If the MIT code was threaded incorrectly, the 'programmer' would have to laboriously go through the woven cores and debug it.

When the crew were approaching the Moon for the landing, various alarms were triggered by the computer. "Whatever information we were looking at [disappeared] and instead it gave us the code number of the alarm," said Aldrin. "It was disturbing and distracting and we didn't know what it meant."

The 1201 and 1202 alarms were obscure codes (and in effect the same error) that flashed up as Armstrong manually attempted to bring the lunar module down. Nobody seemed to know what the codes meant, except for two men: Jack Garman, a NASA computer engineer who had come across the codes before during a practice run, and Steve Bales, who was the Apollo guidance officer. The alarms were being caused by a problem with the landing radar that was stealing precious computing cycles, and the throttle control algorithm was barely working. The computer's 72kb of memory, barely enough to write a sentence in a modern word processor, was struggling as commands into it overflowed. Garman knew that it was safe to continue and allow the computer to handle matters. Its priority scheduling routines, which have formed some of the basis of a lot of modern code, were dumping lower priority tasks in favour of the ones critical to the lunar landing.

As the Eagle approached the surface on automatic, Armstrong and Aldrin realised that the scenery outside of the window didn't look familiar to them. "I think we may be a little long," commented Armstrong, referring to the Eagle having overshot its planned landing site. Looming ahead of them inside a crater was a dangerous-looking boulder field, and coming down on any of those giant rocks the size of houses would have damaged or perhaps even destroyed the Eagle. Armstrong took manual control, using the thrusters to take the Eagle over the boulder field. But now fuel was running low and there was

> "There was a degree of seriousness in mission control that I hadn't even seen in training" **Gene Kranz**

Task Accomplished.....
July, 1969
APOLLO 11
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The flight controllers erupt into applause as Apollo 11 splashes down in the Pacific Ocean on 24 July 1969, successfully completing the mission

The huge, 363-feet tall Saturn V rocket carries three men towards the Moon from Pad A, Launch Complex 39, Kennedy Space Center on 16 July 1969

After a rehearsal mishap when the Lunar Landing Research Vehicle exploded, Neil Armstrong floats safely to the ground

# APOLLO 11

## The mission as it happened

**Abbreviations**
- CSM = Command and Service Module
- CM = Command Module
- SM = Service Module
- LM = Lunar Module

**Apollo 11 crew**
- Neil Armstrong, Commander
- Buzz Aldrin, Lunar Module pilot
- Michael Collins, Command Module pilot

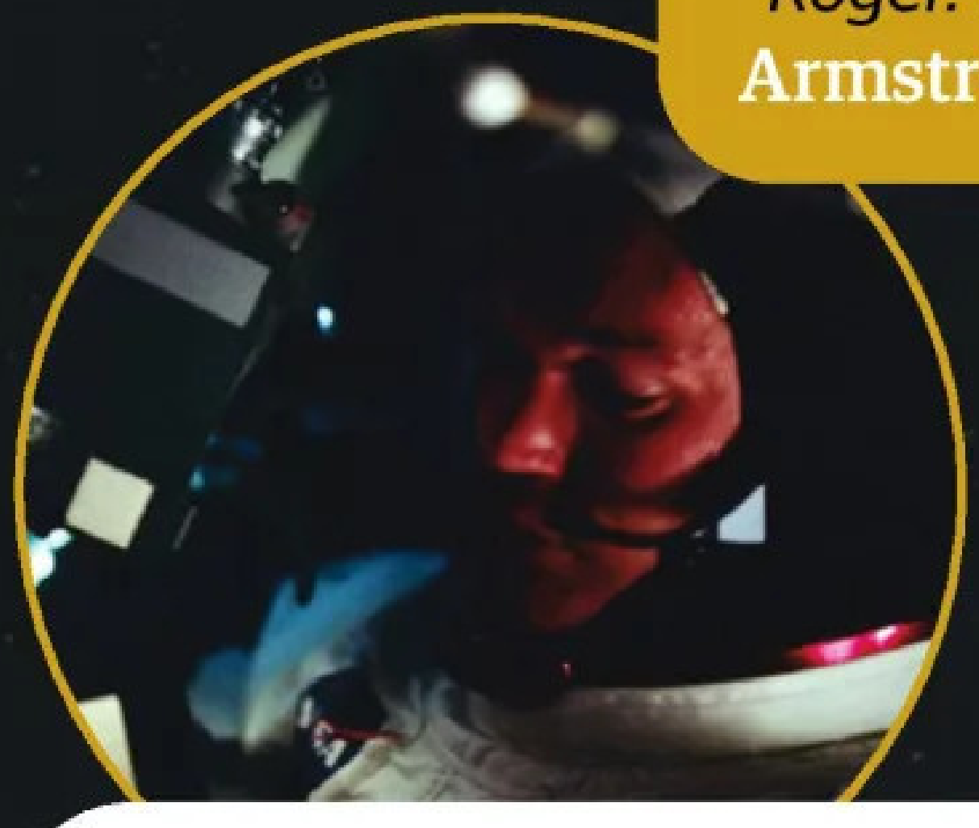
**Mission Control crew**
- Bruce McCandless, CAPCOM
- Charlie Duke, CAPCOM

1

*"Roger. Clock."*
**Armstrong**

2

*"Roger. Roll."*
**McCandless**


3

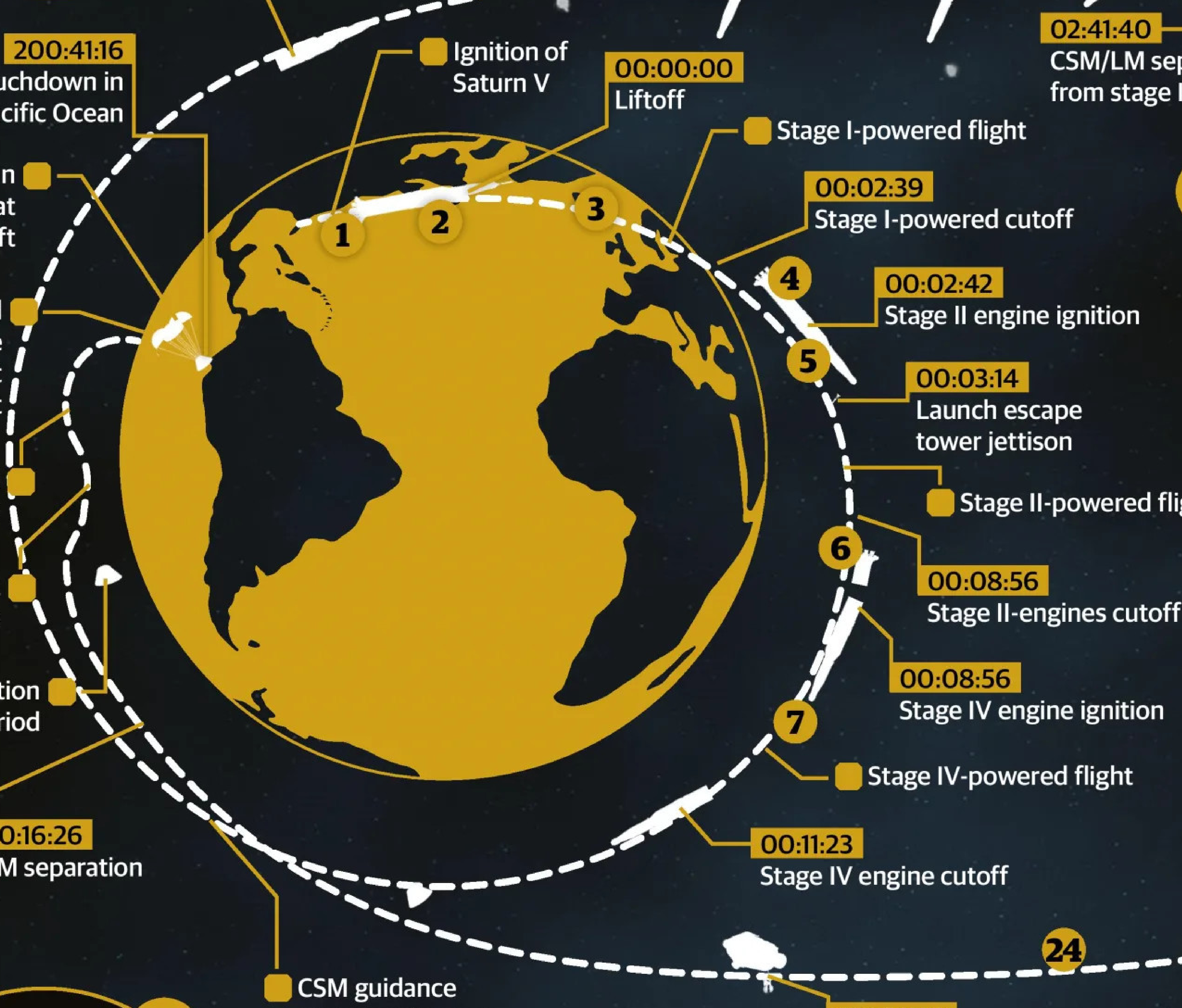
*"Roger. 1 50."*
**Armstrong**

*"Roger. We copy. We'll be configured and waiting for whatever you want to send down."*
**McCandless**

4

5

*"Apollo 11, Apollo 11, this is Houston broadcasting in the blind. Request OMNI Bravo."*
**McCandless**



00:00:00
Liftoff

Stage I-powered flight

00:02:39
Stage I-powered cutoff

00:02:42
Stage II engine ignition

00:03:14
Launch escape tower jettison

Stage II-powered flight

00:08:56
Stage II-engines cutoff

00:08:56
Stage IV engine ignition

Stage IV-powered flight

00:11:23
Stage IV engine cutoff

Ignition of Saturn V

01:35:08
Stage IV engine ignition

01:40:50
Stage IV engine cutoff

01:57:05
CSM guidance system separation and LM adapter, deployment of adapter panels and high-gain antenna

01:58:42
CSM guidance system 180-degree turnaround

02:41:40
CSM/LM separation from stage IV

Navigation sightings

04:43:56
SM ignition

04:44:04
SM engine cutoff

1:52:11:45
SM engine cutoff

46 hours
Systems status checks
Eat and sleep periods
Data transmit periods

199:23:26
SM engine ignition

CSM guidance system reference alignment

200:16:26
CSM separation

Communication blackout period

200,000ft altitude

250,000ft altitude

Heat shield and chute deployed at 24,000ft

Deploy main chute at 10,000ft

200:41:16
Touchdown in the Pacific Ocean

6

*"Roger. Oxygen heaters to AUTO, or you can watch them in the ON position, and oxygen fans manual ON."*
**McCandless**

7

*"This is Houston. Readback correct. Out."*
**McCandless**

20

*"This is too big an angle, Neil."*
**Aldrin**

21

*"Okay. You can make a Mark, Houston. *** deployed."*
**Armstrong**

22

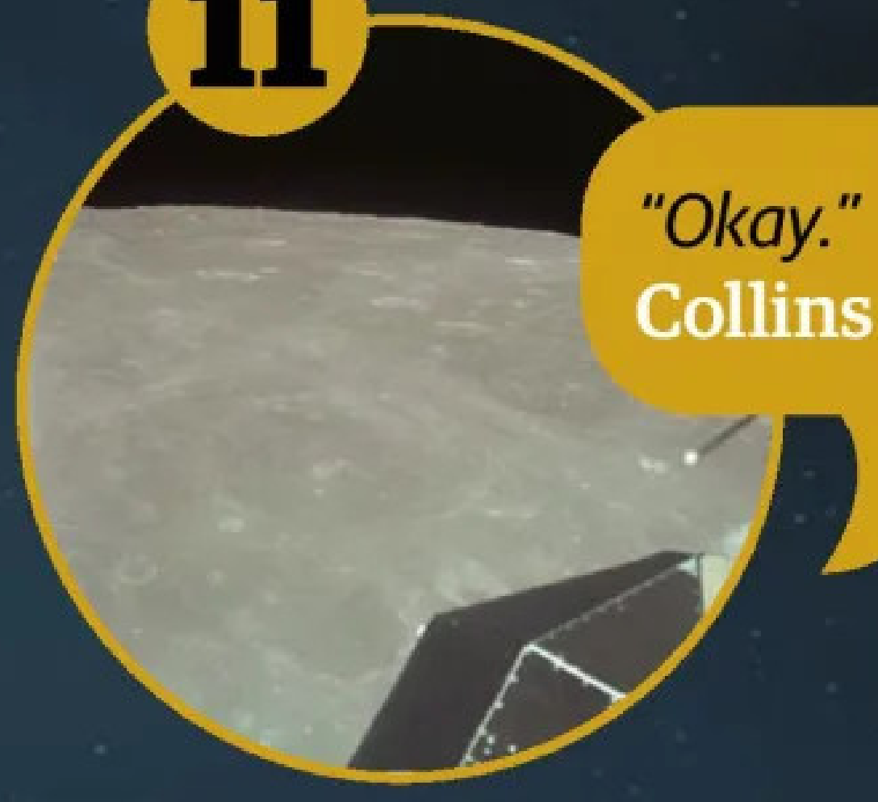
*All right. The doors are open, and it looks like they are going to stay up without any problem.*
**Aldrin**

23

*"Roger"*
**Duke**

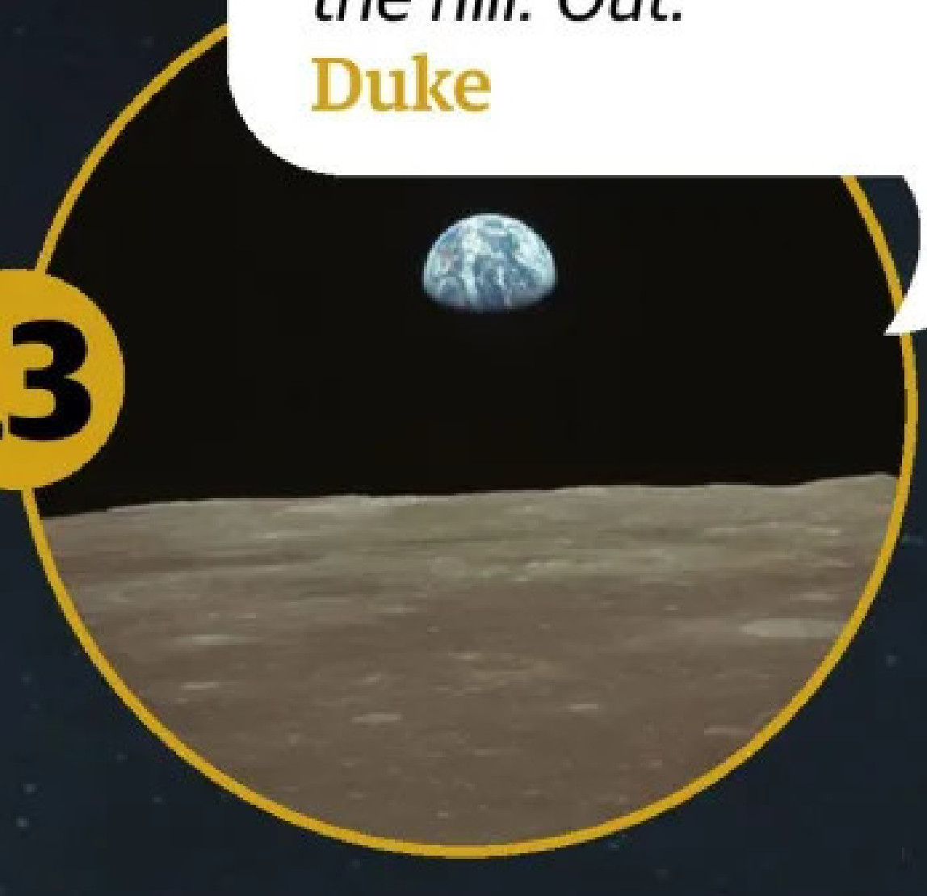
24

*"The Earth is really getting bigger up here and, of course, we see a crescent."*
**Collins**



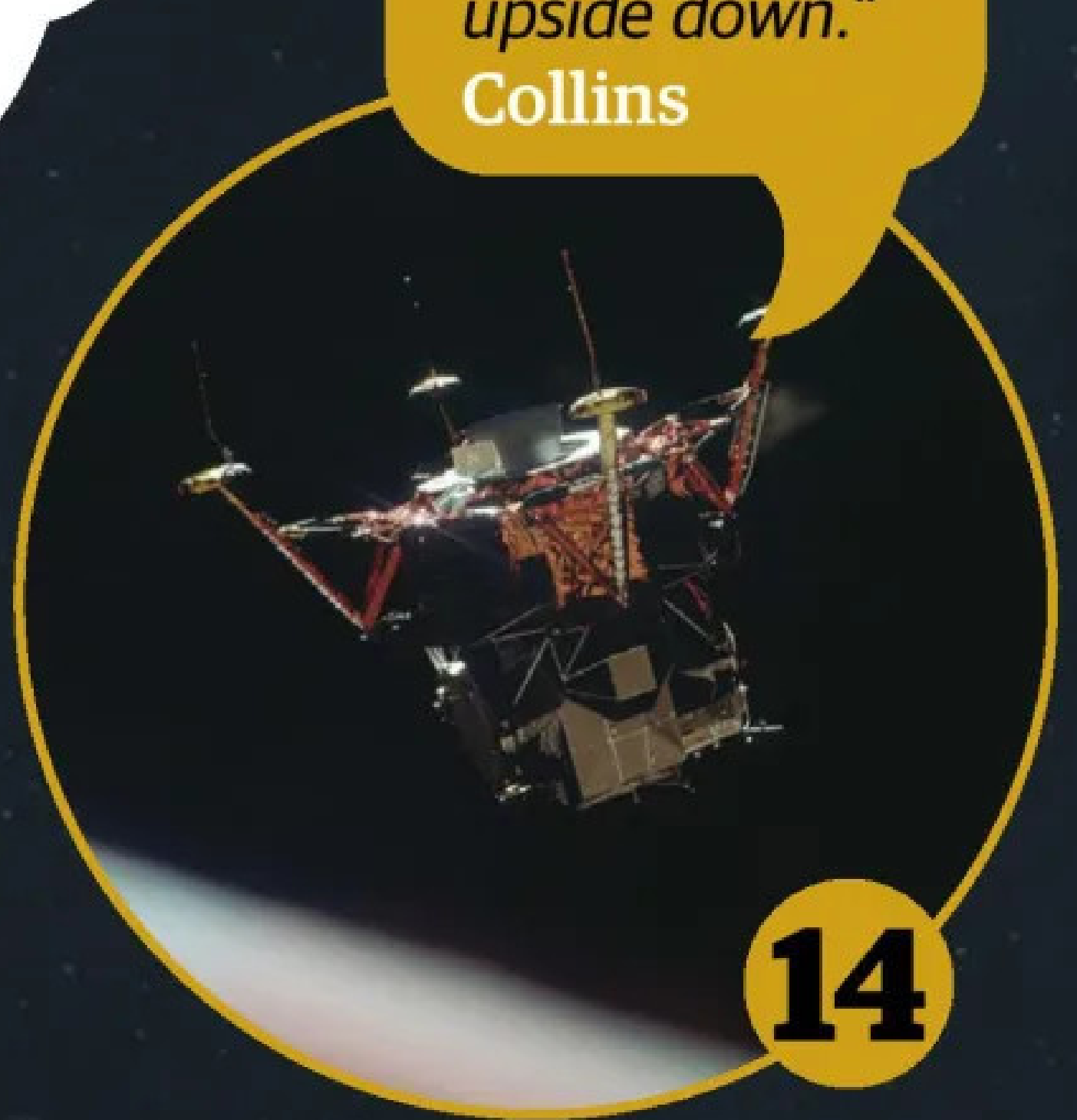
*"Okay."*
**Collins**

*"That's a good, reasonable way of describing it. It appears as though it made a difference just sitting back in the tunnel and gazing at all windows; it makes a difference which one you're looking out of. The camera right now is looking out the number 5 window, and it definitely gives a rosier or tanner tinge."*
**Aldrin**



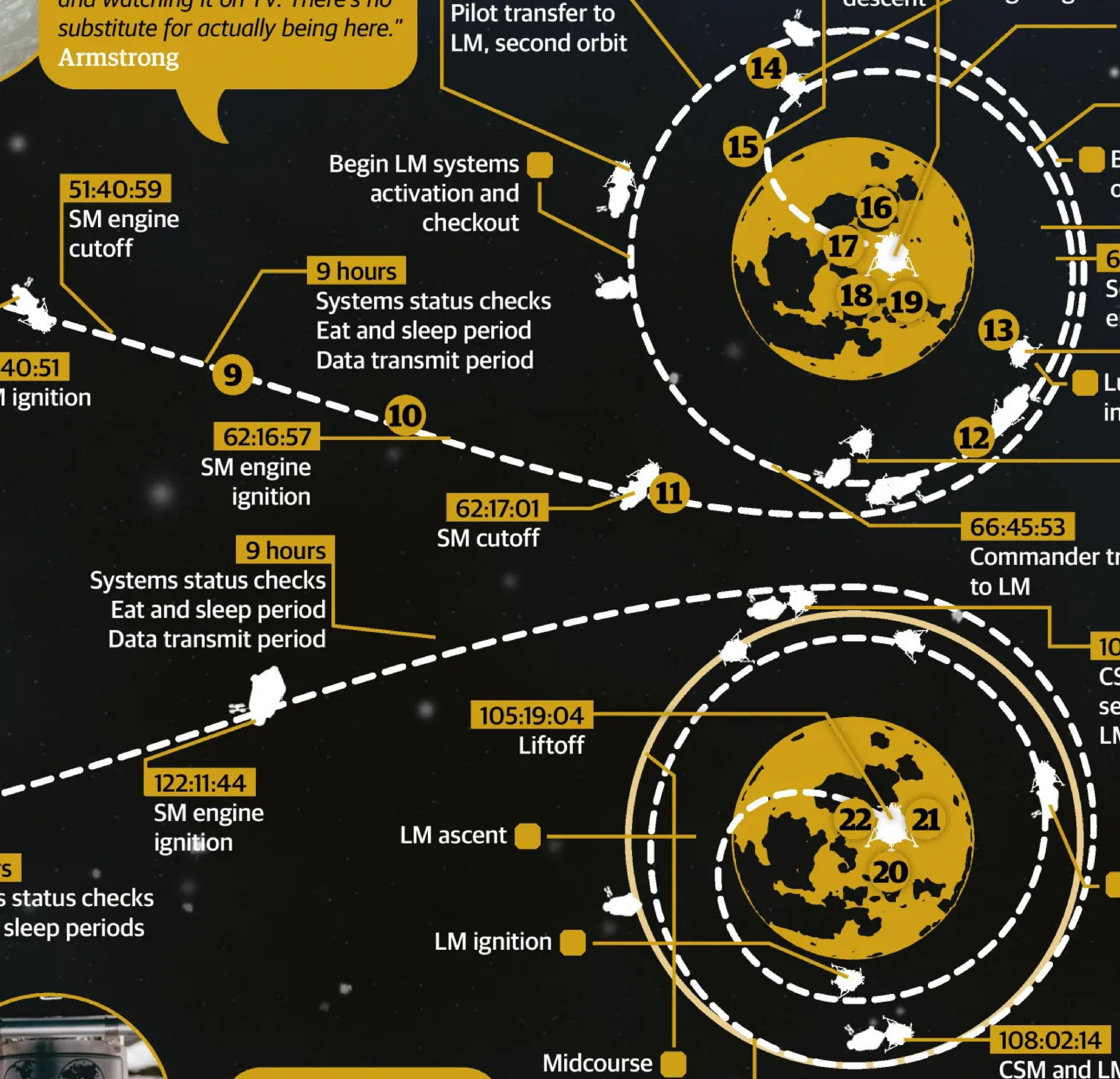
*"Apollo 11, Houston. Thirty seconds to loss of signal. Both spacecraft looking good going over the hill. Out."*
**Duke**

*"I think you've got a fine looking flying machine there, Eagle, despite the fact you're upside down."*
**Collins**



*"Okay, no complaints. I was just curious as to what had happened."*
**Collins**

*"Apollo 11 is getting its first view of the landing approach. This time we are going over the Taruntius crater, and the pictures and maps brought back by Apollo 8 and 10 have given us a very good preview of what to look at here. It looks very much like the pictures, but like the difference between watching a real football game and watching it on TV. There's no substitute for actually being here."*
**Armstrong**



46 hours
Systems status checks
Eat and sleep periods
Data transmit periods

51:40:59
SM engine cutoff

51:40:51
SM ignition

9 hours
Systems status checks
Eat and sleep period
Data transmit period

62:16:57
SM engine ignition

62:17:01
SM cutoff

66:17:43
Pilot transfer to LM, second orbit

64:04:38
Begin navigation sightings

Begin LM systems activation and checkout

Lunar descent

70:37:45
Lunar touchdown

70:27:17
Lunar descent engine ignition

LM guidance system and reference alignment

Begin lunar orbit evaluation

69:29:03
LM descent engine cutoff

Transfer orbit insertion

63:23:27
Service engine cutoff

69:28:31
LM descent engine ignition

Lunar orbit insertion

69:05:32
CSM and LM separate on third orbit

66:45:53
Commander transfer to LM

9 hours
Systems status checks
Eat and sleep period
Data transmit period

109:00:04
CSM and LM separate and LM jettisons

105:19:04
Liftoff

122:11:44
SM engine ignition

LM ascent

Transfer crew and equipment from LM to CSM

28 hours
Systems status checks
Eat and sleep periods

LM ignition

1:52:11:44
SM engine ignition

Midcourse corrections

Rendezvous maneoures

108:02:14
CSM and LM initial docking

*"11, Houston. If that's not the Earth, we're in trouble."*
**Duke**

*"See you later."*
**Armstrong**

*"Roger, Tranquillity. We copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again. Thanks a lot."*
**Duke**

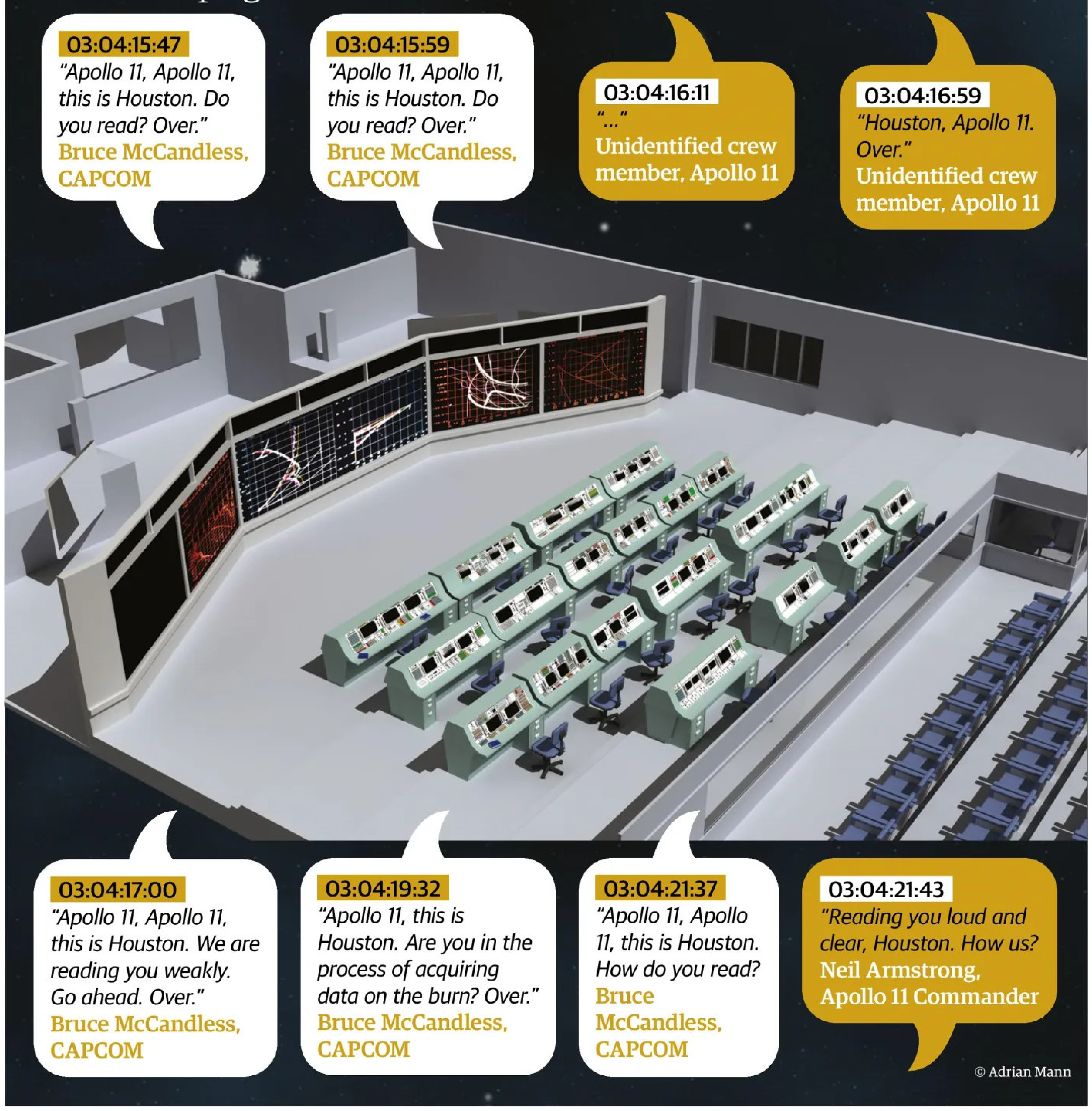
*"The surface is fine and powdery. I can pick it up loosely with my toe. It does adhere in fine layers like powdered charcoal to the sole and sides of my boots. I only go in a small fraction of an inch, but I can see the footprints of my boots and the treads in the fine particles."*
**Armstrong**

*"Contingency sample is in the pocket. My oxygen is 81 percent. I have no flags, and I'm in minimum flow."*
**Armstrong**

*"For those who haven't read the plaque... First there's two hemispheres, one showing each of the two hemispheres of the Earth. Underneath it says "Here Man from the planet Earth first set foot upon the Moon, July 1969 A.D. We came in peace for all mankind." It has the crew members' signatures and the signature of the President of the United States."*
**Armstrong**

## Mission control loses contact with Apollo 11

Alarms, loss of communication and system failures plagued the first mission to land on the Moon



**03:04:15:47**
*"Apollo 11, Apollo 11, this is Houston. Do you read? Over."*
**Bruce McCandless, CAPCOM**

**03:04:15:59**
*"Apollo 11, Apollo 11, this is Houston. Do you read? Over."*
**Bruce McCandless, CAPCOM**

**03:04:16:11**
*"..."*
**Unidentified crew member, Apollo 11**

**03:04:16:59**
*"Houston, Apollo 11. Over."*
**Unidentified crew member, Apollo 11**

**03:04:17:00**
*"Apollo 11, Apollo 11, this is Houston. We are reading you weakly. Go ahead. Over."*
**Bruce McCandless, CAPCOM**

**03:04:19:32**
*"Apollo 11, this is Houston. Are you in the process of acquiring data on the burn? Over."*
**Bruce McCandless, CAPCOM**

**03:04:21:37**
*"Apollo 11, Apollo 11, this is Houston. How do you read?*
**Bruce McCandless, CAPCOM**

**03:04:21:43**
*"Reading you loud and clear, Houston. How us?*
**Neil Armstrong, Apollo 11 Commander**

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The Apollo 11 astronauts, left to right, Neil Armstrong, Michael Collins and Edwin "Buzz" Aldrin inside the Mobile Quarantine Facility are greeted by President Nixon on 24 July 1969

Inside view of the Apollo 11 lunar module shows astronaut Buzz Aldrin during the lunar landing mission, an image taken by Neil Armstrong

> "We started a stopwatch running, with a controller calling off seconds of fuel remaining" **Gene Kranz**

no turning back. Armstrong had to land the Eagle – somewhere, within minutes – or they would be out of fuel and crash.

"We'd never been this close in training," said Kranz. "We started a stopwatch running, with a controller calling off seconds of fuel remaining."

If things were tense in mission control, onboard the Eagle Armstrong and Aldrin had everything under control. With only 13 seconds of fuel left Apollo 11 made its safe landing in the Sea of Tranquillity. History had been made. "Houston, Tranquility Base here," Armstrong radioed home. "The Eagle has landed."

In private, Aldrin took out a small cup, some wine and bread and said Holy Communion. The wine, under one-sixth Earth gravity, apparently curled up in the cup. After reading a section of the Gospel of St John, Aldrin said a few words, with Armstrong respectfully just looking on. NASA had been threatened with legal action by Madalyn O'Hair, an atheist, after the crew of Apollo 8 had read from the Book of Genesis, so Aldrin's heartfelt ceremony never made it to the airwaves. Aldrin though has always been content in the thought that the first food and drink consumed on the lunar surface were communion items.

The original plan had been for the crew to get some sleep, but with that much adrenaline pumping through their veins that was never going to happen. So at 2.39am on the morning of 21 July, Armstrong made his way through the hatch and down the ladder before stepping foot for the first time on the surface of the Moon and saying those immortal words, "That's one small step for [a] man, one giant leap for mankind."

After exiting the lunar module, Armstrong and Aldrin only had a few hours to not only collect precious rock samples, but also deploy a series of experiments on the lunar surface. Solar wind experiments, a laser retro-reflector that is still used to this day to measure the Earth-Moon distance, seismometers, and more were all deployed. Armstrong is cited as saying he felt like a five-year-old in a candy store, with not enough time to do all the things he wanted to.

Standing on the Moon must have been an incredible experience. Aldrin described the scene around him as one of "magnificent desolation," adding that, "You could look at the horizon and see very clearly because there was no atmosphere, there was no haze or anything."

As Armstrong walked around setting up instruments and picking up rocks, Aldrin hopped around on the surface, testing what the best way to move about in the low gravity was. Most of the pictures taken during the landing are of Aldrin on the surface; barely half a dozen show Armstrong, and none clearly. That's because Armstrong had the camera for most of the Moon walk.

While on the surface, the crew also had terrific problems with the American flag. It had a telescoping boom arm to hold it out in lieu of any wind to hold it up. The two crew wrestled to get the boom arm to extend fully, but it would not, so the flag had a small kink in it. They also found that it was almost impossible to get the flag pole to go deep enough into the ground and, in the end, they only just managed to get it to stay upright. Both of the crew worried it would fall over live on TV, and probably as President Nixon was on the phone to them. But it remained upright during the broadcasts and telephone calls.

After collecting their rocks and clambering back into the lunar module, the crew took off their boots and backpacks, and began to throw anything not of vital importance back on to the lunar surface. This included urine bags, empty food packs, empty cameras and so on. But to the crew, they were just getting in the way and not needed.

There was time for one final crisis. The interior of the lunar module was cramped and, moving around in their bulky spacesuits, one of the astronauts had knocked out the switch for the circuit breaker that fired the ascent rocket that would take them home.

This was a real bottleneck moment for the mission. "If for some reason the ascent engine didn't work, there was no way to rescue the crew," said Kranz. Armstrong and Aldrin would be stranded on the Moon. The concern was so serious that President Nixon had a speech prepared, while mission control would close down communications with Armstrong and Aldrin after a clergyman had "condemned their souls to the deepest of the deep." Without that circuit breaker the crew were facing that lonely fate, but their training would not have allowed them to give up. "Rather than worry about things like that, we'd face them when the time came and we'd work as hard as we could to fix the problem until our oxygen ran out," said Aldrin.

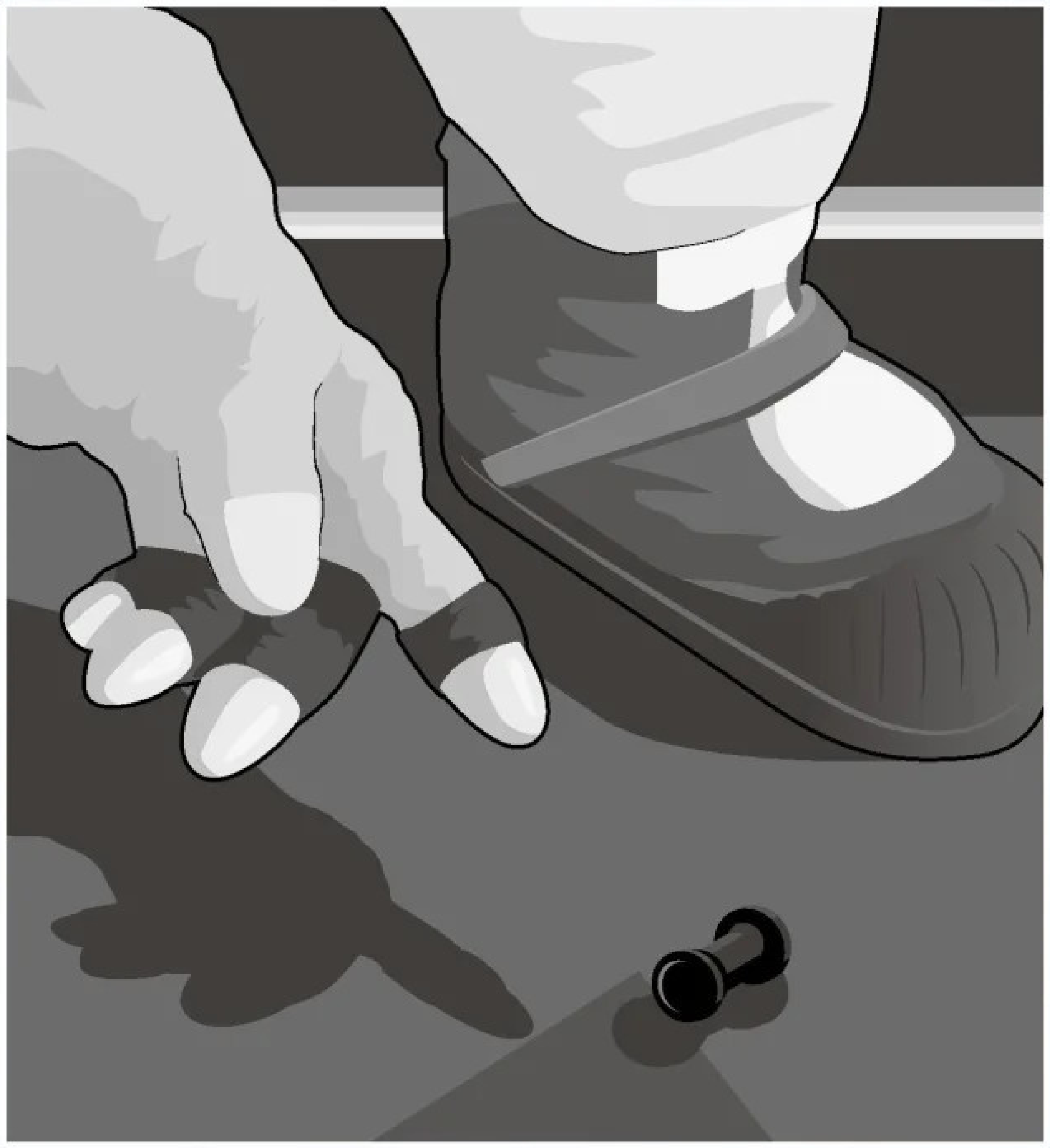
In the end, the solution was remarkably simple. Jabbing the end of a pen into the slot where the broken switch had been, Aldrin was able to push the circuit breaker in. The ascent rocket fired and the two Moon-walkers were on their way home, via a rendezvous with Michael Collins in the command module. As the Eagle took off, the flag finally did blow over, and to this day it lays flattened, bleached out by solar radiation.

Over 50 years since that first successful landing on the Moon, stories still come out, not just from the thoughts of the crew, but also the almost 400,000 others who worked on the mission, from 'the guy sweeping the floor' at Cape Canaveral, to the flight directors and flight controllers, without whom the historic landing may never have happened. With our return to the Moon still some way off, these stories are all we have for now.

**HOW TO...**

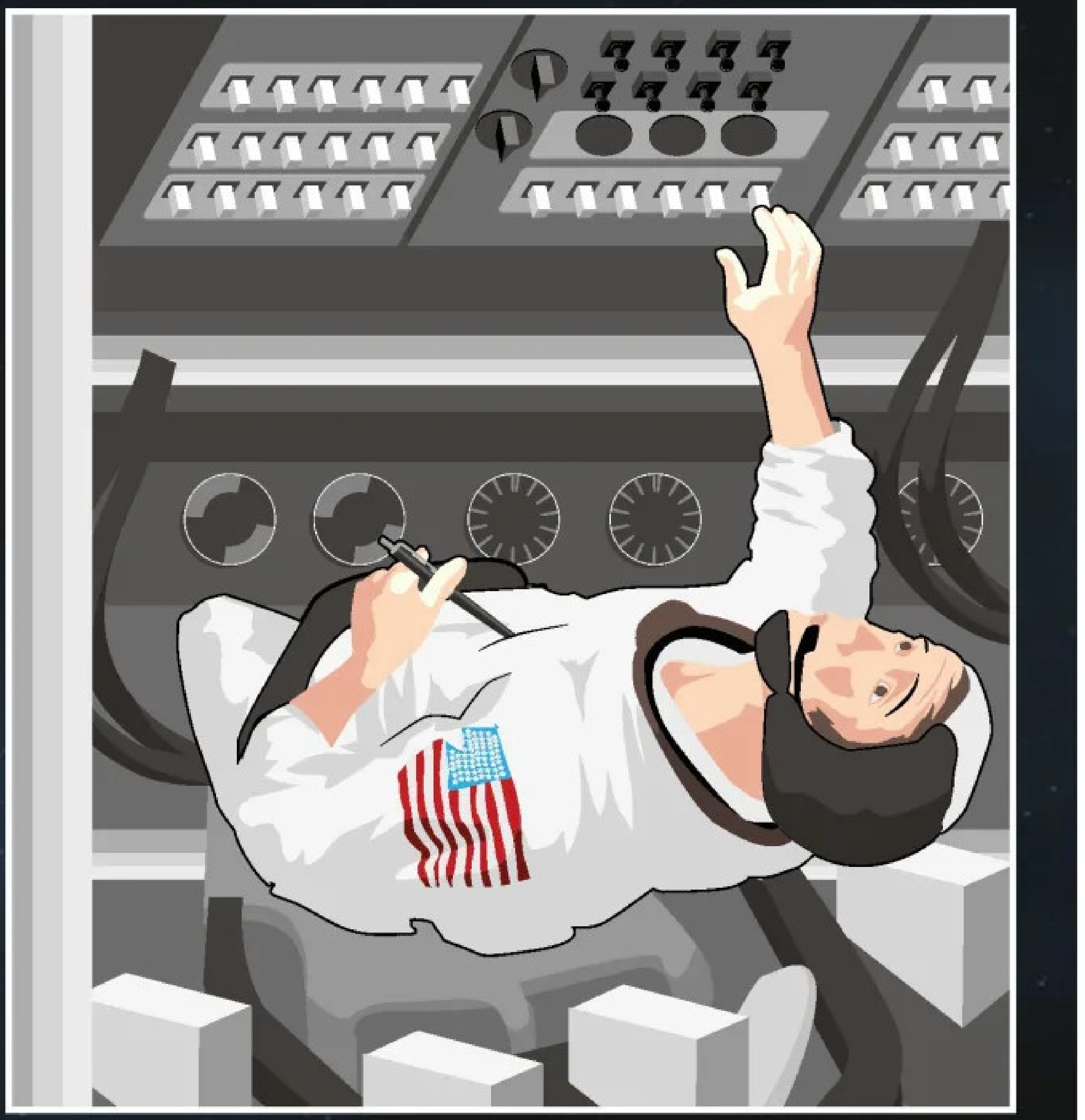
## Use a felt-tipped pen to escape from the Moon

After a circuit breaker switch broke off in all the to-ing and fro-ing in the cramped environment of the lunar module, Buzz Aldrin had to improvise in order to escape the Moon



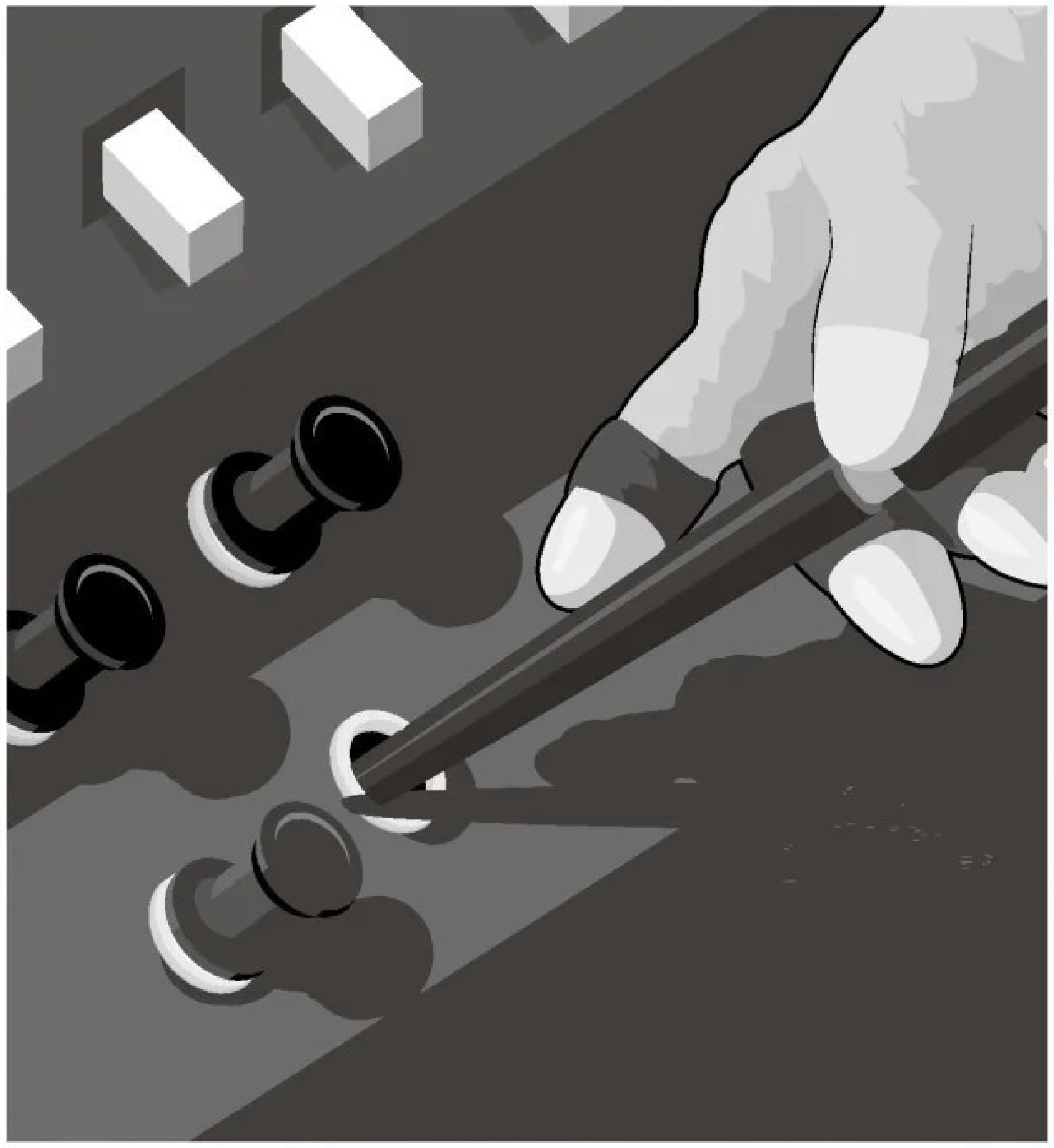
### 1 Astronauts locate broken circuit breaker switch

Neil Armstrong and Buzz Aldrin were gathering themselves into the landing module to start the return back to Earth when Aldrin noticed something lying on the floor – the circuit breaker switch had gotten bumped and had broken off.



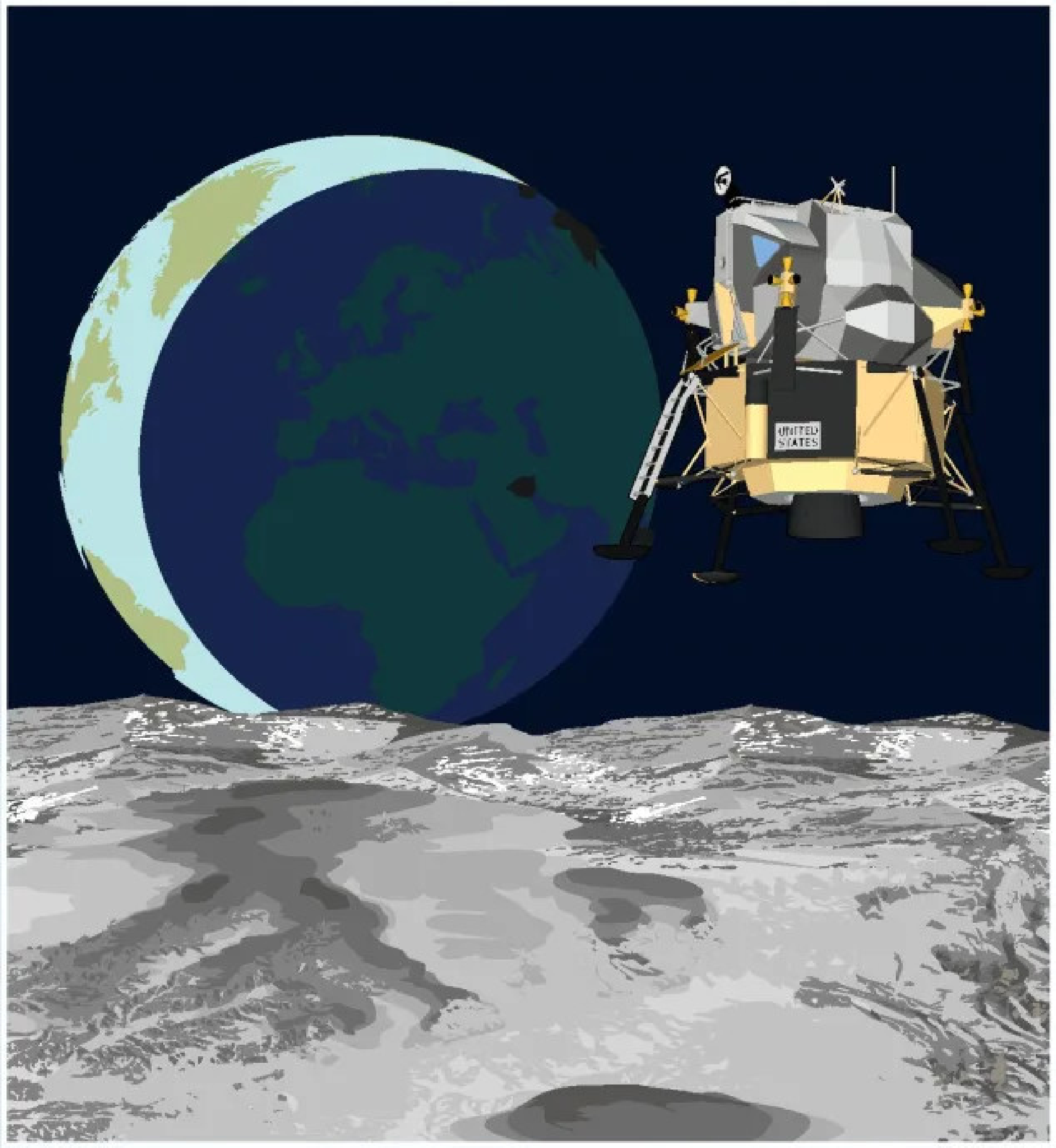
### 2 Aldrin and Armstrong alert mission control

This switch needed to activate the ascent engine to lift them off the Moon. Telling mission control, they tried unsuccessfully to catch some sleep but, by the following morning, NASA had no solution, with Aldrin forced to come up with some kind of fix.



### 3 Saved by a felt-tipped pen

Since the circuit was electrical, sticking his finger or anything metal in wasn't possible. Instead, Aldrin found a felt-tipped pen in his shirt and inserted it into the opening where the circuit breaker switch should have been. He moved the countdown procedure up by a couple of hours.



### 4 Lift off!

The circuit breaker held, allowing both Aldrin and Armstrong to lift off from the surface of the Moon and intercept Michael Collins, who was in orbit around the Moon.

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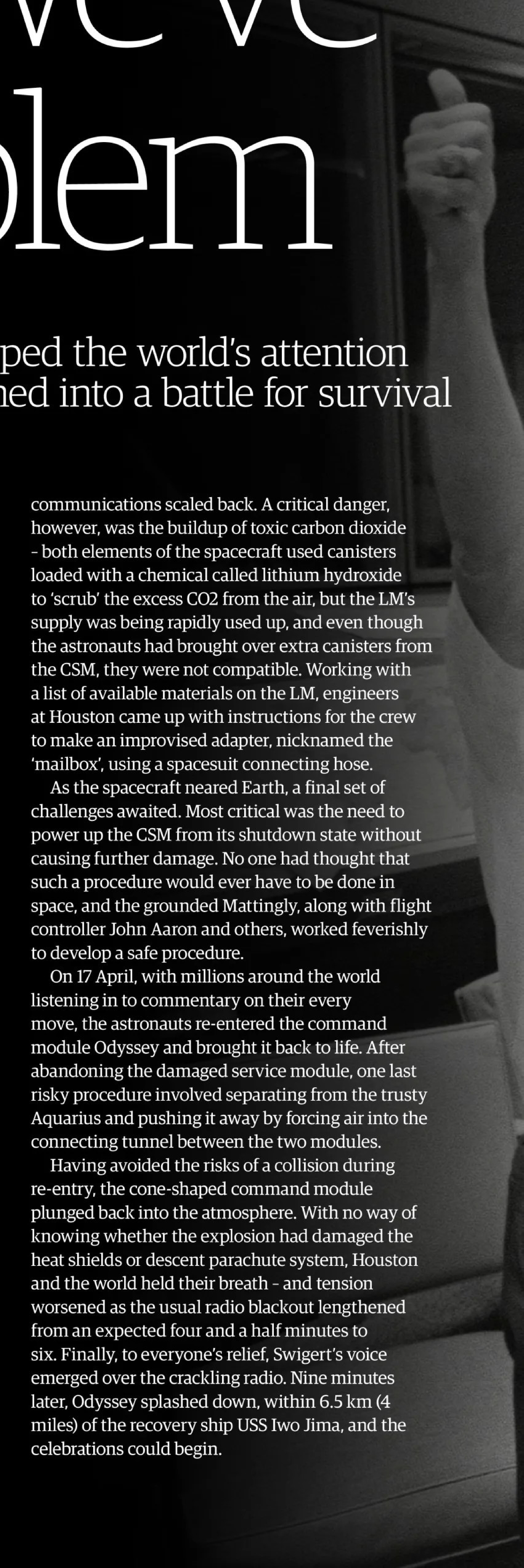


# Houston, we've had a problem

## Planned as NASA's third lunar landing, Apollo 13 gripped the world's attention for all the wrong reasons, as a flight to the Moon turned into a battle for survival

On 11 April 1970, as Apollo 13 blasted clear of Cape Canaveral right on schedule, none of those on board could have foreseen the struggle for survival they were soon to encounter. The crew included two freshman astronauts – Command Module pilot Jack Swigert and Lunar Module pilot Fred Haise, but was led by one of NASA's most experienced spacefarers, Gemini and Apollo 8 veteran Jim Lovell (Lovell and Haise had been backup crew for the Apollo 11 mission, while Swigert was a late replacement for Ken Mattingly, who had been grounded as an infection risk after one of his children contracted rubella).

The first two days of their cruise towards the Moon were routine, but 56 hours into the flight, a routine request to stir the service module's fuel tanks rapidly spiralled into a crisis. As Swigert triggered the stirring motor, a loud bang echoed through the craft and warning lights flashed to indicate that one of the module's power circuits was rapidly draining. Swigert and Lovell reported back to mission control with typical understatement: "Okay Houston, we've had a problem here."

Now the spacecraft began shaking from side to side, and as Lovell struggled to stabilise it, he spotted a jet of gas escaping into space. On-board gauges and telemetry signals received at Houston showed one of the service module's two oxygen tanks as empty, and two of the three batteries designed to power the command and service modules (CSM) throughout the mission were now flat. Even worse, pressure in the second oxygen tank was falling.

Now, the problem became clear – the spacecraft oxygen tanks provided not just fuel and air, but were also linked to a fuel cell that charged the batteries. An explosion (later traced to poorly insulated wiring) had ruptured the system, but the tanks were still pumping oxygen to it.

With Apollo 13 some 330,000 km (205,000 miles) from Earth and still Moon-bound, the crew and staff at mission control, led by flight director Gene Kranz, had to think fast. After shutting down the fuel cell to preserve the remaining oxygen, their first thought was to draw power from the independent systems on the Lunar Module (LM) Aquarius, but this idea was soon abandoned, as the demands on the LM's limited batteries would be too high. Instead, the crew were ordered to use Aquarius as a 'lifeboat', transferring supplies into the cramped vehicle (only intended for two astronauts), before shutting down the CSM systems completely to preserve them for return to Earth, and locking themselves in.

Within three hours, the immediate crisis was over, but the struggle to get the crew safely back to Earth was just beginning. NASA's contingency plans to abort a mission in this phase called for jettisoning the LM and also required a fully fuelled CSM, so were obviously out of the question. Instead, Kranz and his team realised the only option was to swing the entire spacecraft around the far side of the Moon, using the LM's small engines to enter a return trajectory. The timing of these engine burns would be critical – 30.7 seconds was needed on lunar approach to put the spacecraft into a 'free return' trajectory (where the Moon's gravity would effectively swing the spacecraft around and hurl it back towards Earth), and then a longer burn during return would speed up re-entry by ten hours (so that splashdown would occur in the Pacific rather than the Indian Ocean). As the crippled spacecraft swung around the far side of the Moon on 15 April, and communications with Earth were temporarily cut off, its crew set an unwanted new record as the furthest humans from Earth, some 400,171 km (248,655 miles) away.

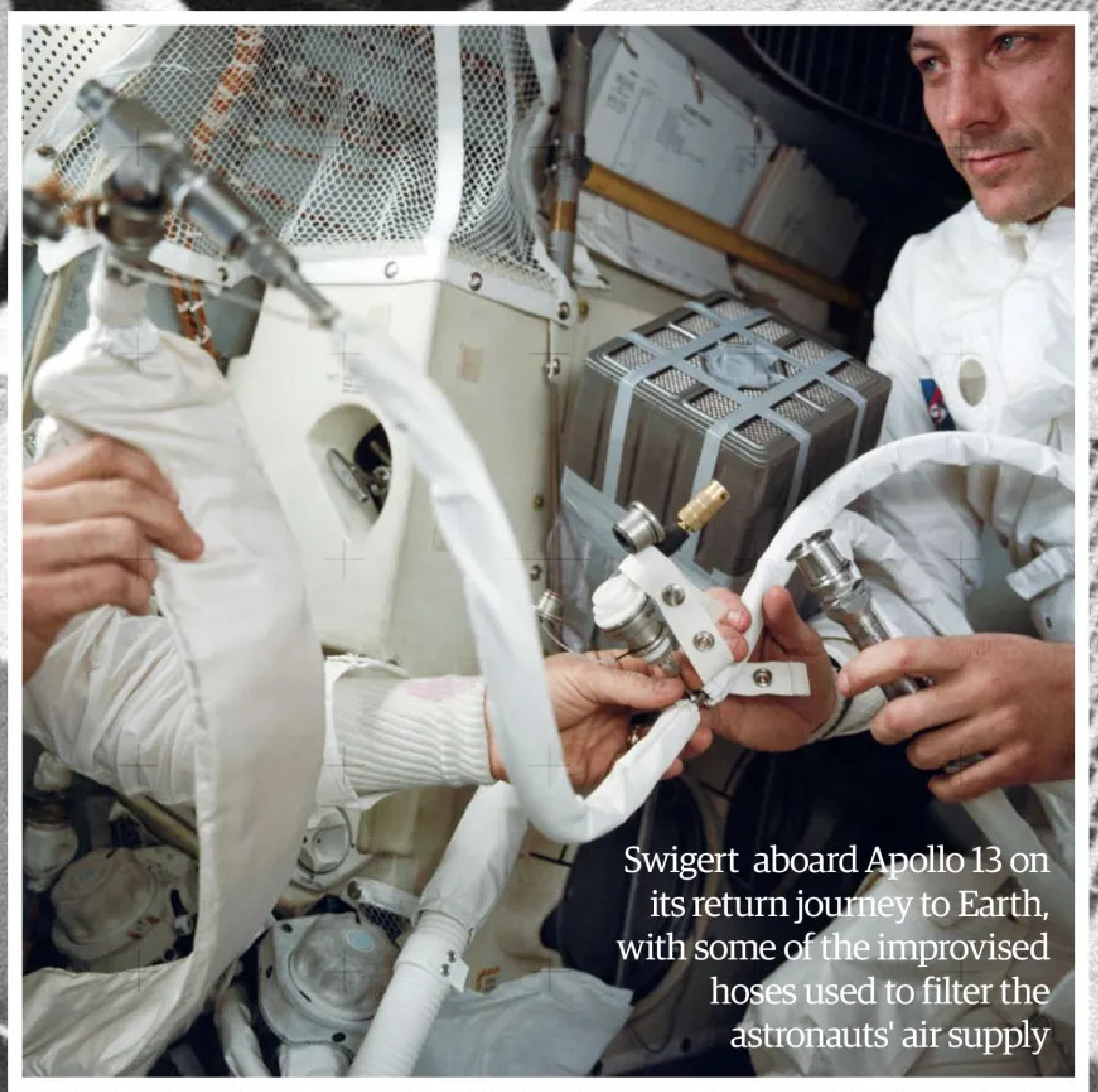
Sealed into the cramped Lunar Module, survival for the crew now became the overriding priority; all four ground-control shifts at Houston were drafted in to look at various aspects of the problem. Oxygen supplies were sufficient even with three men on board, but water was limited, and power consumption had to be reduced, so television transmissions were abandoned and even radio communications scaled back. A critical danger, however, was the buildup of toxic carbon dioxide – both elements of the spacecraft used canisters loaded with a chemical called lithium hydroxide to 'scrub' the excess CO2 from the air, but the LM's supply was being rapidly used up, and even though the astronauts had brought over extra canisters from the CSM, they were not compatible. Working with a list of available materials on the LM, engineers at Houston came up with instructions for the crew to make an improvised adapter, nicknamed the 'mailbox', using a spacesuit connecting hose.

As the spacecraft neared Earth, a final set of challenges awaited. Most critical was the need to power up the CSM from its shutdown state without causing further damage. No one had thought that such a procedure would ever have to be done in space, and the grounded Mattingly, along with flight controller John Aaron and others, worked feverishly to develop a safe procedure.

On 17 April, with millions around the world listening in to commentary on their every move, the astronauts re-entered the command module Odyssey and brought it back to life. After abandoning the damaged service module, one last risky procedure involved separating from the trusty Aquarius and pushing it away by forcing air into the connecting tunnel between the two modules.

Having avoided the risks of a collision during re-entry, the cone-shaped command module plunged back into the atmosphere. With no way of knowing whether the explosion had damaged the heat shields or descent parachute system, Houston and the world held their breath – and tension worsened as the usual radio blackout lengthened from an expected four and a half minutes to six. Finally, to everyone's relief, Swigert's voice emerged over the crackling radio. Nine minutes later, Odyssey splashed down, within 6.5 km (4 miles) of the recovery ship USS Iwo Jima, and the celebrations could begin.

Apollo 13 flight directors celebrate the successful splashdown of the Odyssey after the damaged craft's harrowing flight



Swigert aboard Apollo 13 on its return journey to Earth, with some of the improvised hoses used to filter the astronauts' air supply

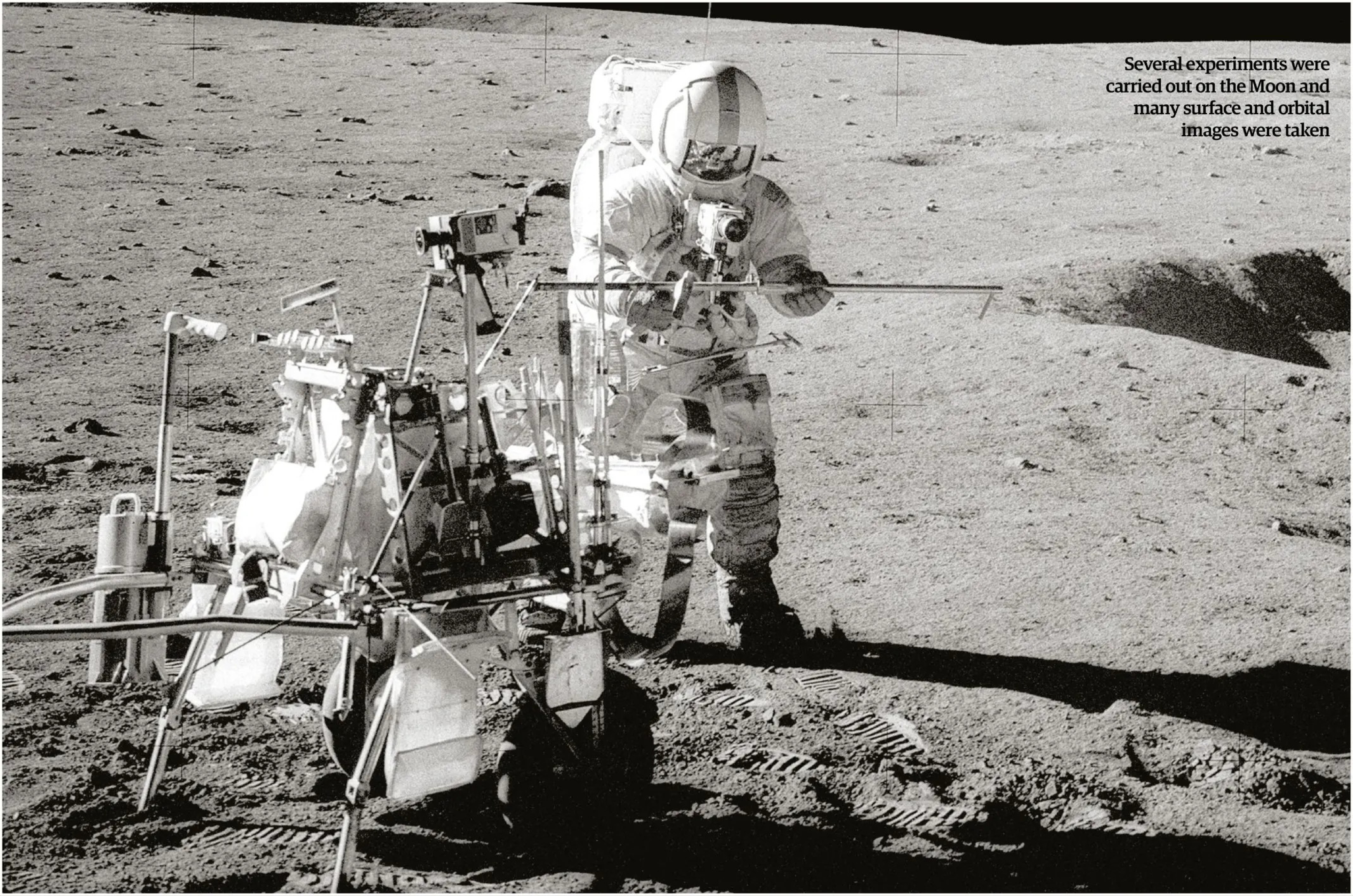
# Apollo 14's Moon landing

## In February 1971, three rookies landed on the Moon's surface and played lunar golf

When Apollo 14 launched on 31 January 1971, it was not without trepidation. The previous year, the third lunar landing mission – Apollo 13 – had failed to make it to the Moon when an oxygen tank exploded. The crew members survived but serious questions were being asked about the viability of manned missions.

Apollo 14 didn't get off to the best of starts either. Clouds and rain forced a delay of 40 minutes and two seconds, while commander Alan Shepard, command module pilot Stuart Roosa and lunar module pilot, Edgar Mitchell, had problems with the docking latches. But, they finally landed on the Moon on 5 February 1971 in the Fra Mauro formation, with Shepard and Mitchell spending 33.5 hours on the lunar surface. Two extravehicular activities traversed 3.5 kilometres (2.2 miles) over 13 locations, carrying out ten experiments over nine hours. And, although an attempt to tow a two-wheeled trolley full of tools and cameras 1.6 kilometres (one mile) up the steep slopes to the rim of Cone Crater was abandoned, the mission was deemed an overall success. For the trio, it was a particular triumph, as they had been dubbed "the three rookies" due to their lack of spaceflight time and experience.

Indeed, only Shepard had flown before – which was in 1961, as the first American in space. To celebrate, he had his own moment of glory. Just before the crew readied for home, Shepard grabbed a six-iron and hit some golf balls far into the distance. It was, it has to be said, the ultimate Moon shot.



Several experiments were carried out on the Moon and many surface and orbital images were taken

During their Apollo 14 mission to the Moon, Alan Shepard and Edgar Mitchell spent a total of 33.5 hours on the lunar surface

© NASA

# Apollo 15's record-breaking pilot

Often referred to as Earth's most isolated human being, Apollo 15's Command Module pilot Al Worden tells the story of his lonely space flight

**Interviewed by Jonathan O'Callaghan**

Worden's first and only mission to space was Apollo 15 in 1971

**BIOGRAPHY**

**Al Worden**

Alfred Merrill Worden was the Command Module pilot for NASA's Apollo 15 lunar mission, which launched on 26 July 1971. He remained in lunar orbit while his fellow crew Dave Scott and Jim Irwin explored the surface for three days, the longest stay on the Moon at the time. From his position in lunar orbit Worden photographed and studied the Moon, and during his orbit he is said to have travelled farther out than anyone else, earning him the accolade of Earth's 'most isolated human being'.

**How did it feel to get selected as an astronaut by NASA in 1966?**

It was probably one of the best days of my life when I got the phone call. You're venturing off into something that very few people have ever done. You've competed with 700 or 800 other [applicants] and you're kind of on top of the pile. It would be like, if you're a soccer fan, getting a call from the best team in the country telling you you're going to be one of their players and they're going to take care of you. It's kind of like that, it'd be a great day but that's when the work starts.

**Were you friendly with the other Apollo astronauts? Were they competitive?**

Oh yeah. There was a lot of friendly competition I would say [because] you're trying to get on a flight and you want to beat everybody else, but at the same time you're always training together. Of course, now that we are all retired we have become much more friendly than we were back then.

**What was the training process like?**

There was lots of it; the training kind of covered everything. Not only the engineering and the technical and the flying part, but other parts too like studying geology because we had to know what we were doing once we got up to the Moon. We had a lot of very interesting trips like to the desert, the jungle and Iceland to look at geology but also to look at different climates because there was a survival aspect. If we didn't come back in the atmosphere at the right place, if we lost control and ended up in a jungle in South America for example, we had to learn how to survive long enough for them to come pick us up.

**Were you happy to stay in lunar orbit as the Command Module (CM) pilot, or did you want to walk on the Moon?**

Well, back in those days the way to become a commander on a flight [who walked on the Moon] was to be the CM pilot [first]. Like Dave Scott, he was a CM pilot on Apollo 9 before he became the commander on our flight, and that was basically the rotation.

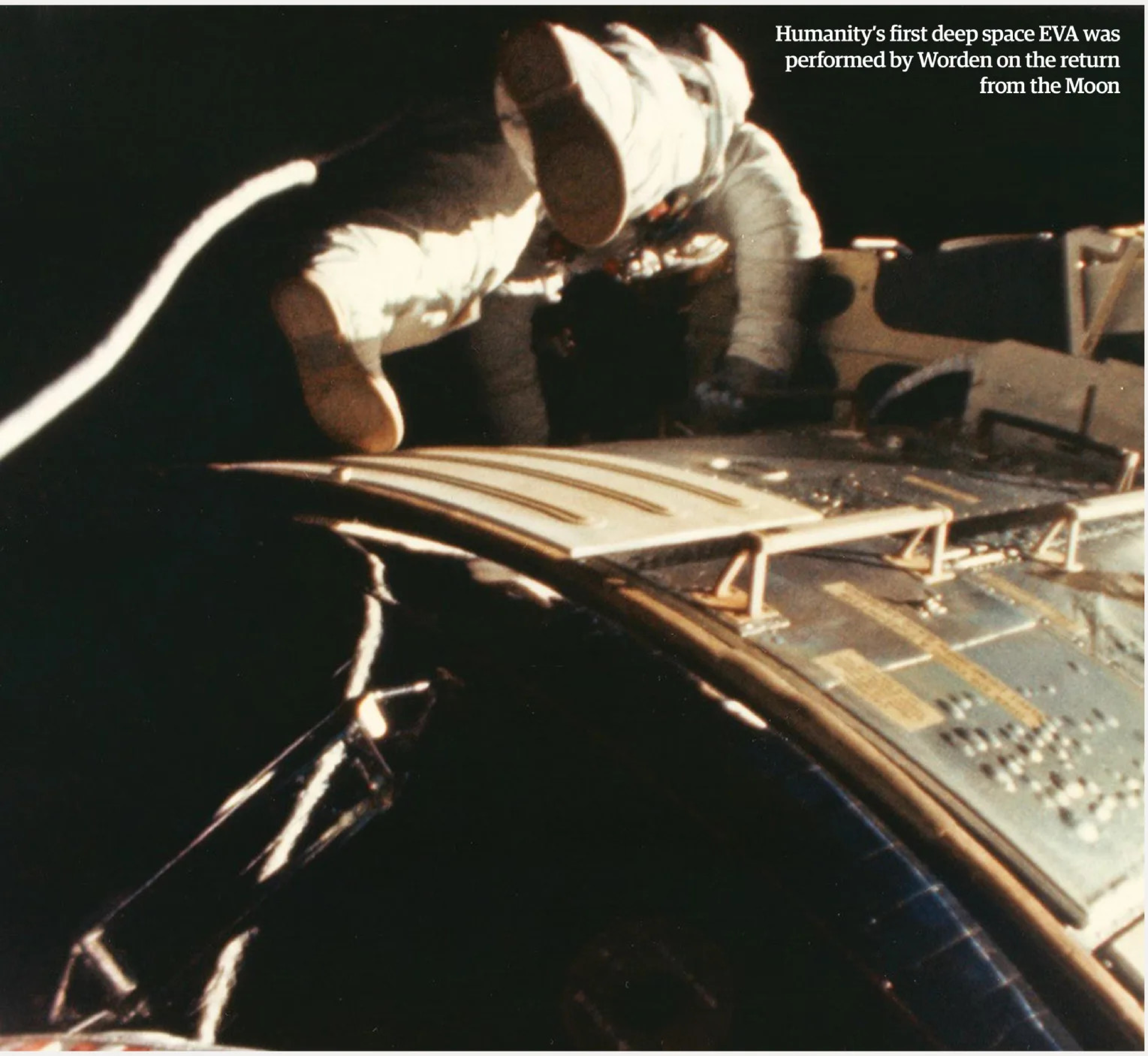
**So were you disappointed when your chance to go to the surface on Apollo 18 was cancelled?**

Oh yeah. There goes the chance to go again. I thought it was kind of dumb at the time, but I understood that NASA had to take that money and put it into the Space Shuttle programme, which wouldn't fly for another ten years, but you've got to build those programmes a long time before they fly.

**Why are you regarded as the most isolated human being of all time?**

I was further away from the guys [on the surface of the Moon] than anybody but we're talking a matter of miles. All the CM pilots had the same deal, they were isolated to a certain extent. I was the first one to go for three full days by myself in lunar orbit and I was a little higher on

"I think eventually the day will come when we're going to have a spacecraft that will go way, way beyond even the Solar System"



Humanity's first deep space EVA was performed by Worden on the return from the Moon

Worden photographed and mapped 25 per cent of the Moon while in lunar orbit

the back side of the Moon than the others, so I guess they say I'm the most isolated. It's in the *Guinness Book of World Records*, anyway.

**Were there any moments by yourself when you were worried something might go wrong?**
No, you don't think about those sorts of things on a flight like that. There's always something that could happen, it's like flying an aeroplane, but you don't focus on that, you don't let yourself brood about that stuff.

**What were your highlights from the mission?**
I'd say seeing the Moon for the first time, and seeing Earth for the first time from the Moon. Those were pretty spectacular sights.

**Since the Apollo missions, do you think space exploration has progressed forwards?**
Well, it's hard to tell. I think right now they're focusing on getting commercial spacecraft to fly people to the space station, but in the background there is a long-range programme with [the Space Launch System rocket] and [the Orion spacecraft] that will eventually allow us to go beyond Earth orbit, like going to Mars. But right now is not an active part of launching because we're between programmes I guess, and so it's going to be a few years before they get the long-range exploration going with the new spacecraft and I would expect it's going to be another 10 or 15 years before we get back into the exploration business.

**Are we moving in the right direction?**
I think eventually we're going to have to do something a little different than just that gumdrop-shaped capsule because there are some problems with re-entry and that sort of thing, you have to be very careful. But the day will come when we're going to have spacecraft that'll go way, way beyond even the Solar System, so that'll take a different shape. But in the meantime we've got Orion, which is basically an enlarged Apollo spacecraft, and it can do the next step.

**And, finally, tell us about the new flight suits you're releasing.**
We're producing very authentic Apollo jackets, a testament to the programme but also a very high-quality jacket. It's the same weave that was in the [original] Apollo jacket, and the cuffs and the zippers and the stamps are all authentic from the same manufacturer that applied those things to the flight jackets over 40 years ago. It harks back to an era in spaceflight that was really wonderful.

## Falling To Earth

FALLING TO EARTH
AN APOLLO 15 ASTRONAUT'S JOURNEY TO THE MOON
AL WORDEN
WITH FRANCIS FRENCH

Price: £11.75/$17.95
Worden's autobiography *Falling To Earth* tells the story of his time at NASA, and is available now. He also released a limited number of authentic Apollo astronaut jackets (pictured), you can find out more at **www.alworden.com/jacket.htm**

© NASA; Steven Pidcock

# The story of Skylab

**Written by Jonathan O'Callaghan**

## NASA's first space station provided the groundwork for prolonged space habitation before its untimely demise

In 1971, the Soviet Union launched the world's first space station, Salyut 1, to global acclaim. Not one to be outdone by the USSR, NASA already had plans in the works for a bigger and better example that would lay the groundwork for future space stations, including Mir and the ISS. Enter Skylab, NASA's pioneering space settlement of the Seventies.

During the Fifties, rocket scientist Wernher von Braun, alongside other space visionaries, outlined his plan to build a giant rotating space habitat that would house many people in orbit. The proposal, although ambitious, was seriously considered by NASA and other agencies as a means to explore beyond Earth orbit, specifically the Moon. Following the creation of Project Apollo, however, which did not require in-orbit assembly, von Braun's ambitious plans were scrapped.

NASA, however, still saw the benefits of launching a space station, especially for scientific purposes and to ascertain the ability of humans to operate for a prolonged period in space. Therefore, in 1963, NASA and the Department of Defense (DoD) decided to co-operate in the building of a space station, although their objectives proved to be different and NASA decided to go ahead with construction of Skylab alone.

Skylab was launched atop a modified Saturn V rocket on 14 May 1973, the last time this iconic rocket ever launched. The modifications were the upper stage of the rocket. Skylab was basically a refurbished third stage of a rocket gutted out and made into an orbital workshop, which was placed inside the upper stage of the Saturn V rocket. Astronauts launched to the station in an Apollo Command and Service Module atop a smaller Saturn 1B rocket. Unlike the ISS, which took over 12 years to build, Skylab was built in its entirety and required only one unmanned launch.

Less than two weeks later, on 25 May 1973, the first three-manned crew (Charles 'Pete' Conrad, Paul Weitz and Joseph Kerwin) launched to the station. However, their arrival was not devoid of problems. During the unmanned launch of Skylab a micrometeoroid shield had torn off the station. Not only did this rip off one of the solar panels and prevent the other from deploying, but it also left the station with no defence against incoming solar radiation. This raised the temperature on Skylab to 52 degrees Celsius (126 degrees Fahrenheit). When the first crew arrived, their first task was to deploy a makeshift parasol with a spacewalk to lower the temperature and deploy the stuck solar panel, bringing the station up to near full power.

With the problems overcome, Skylab was ready to fulfil its promise. One of the most important tasks of the Skylab missions was to see how humans coped with prolonged stays in space. The three astronauts performed daily biological tests, taking turns to act as the 'guinea pig' as the others monitored their bodies. These ranged from basic physical exercises to blood tests and other medical examinations. The astronauts' days lasted from 6am to 10pm (Houston time), during which they each conducted solar observations and other experiments. The crew also had a number of experiments designed by students to carry out, which were generally a bit more light-hearted than those arranged by NASA. These included observing the motion of a blob of water in zero-gravity and playing catch to test hand-eye co-ordination.

> "Skylab moved into a state of freefall and, on 11 July 1979, it began to re-enter the Earth's atmosphere"

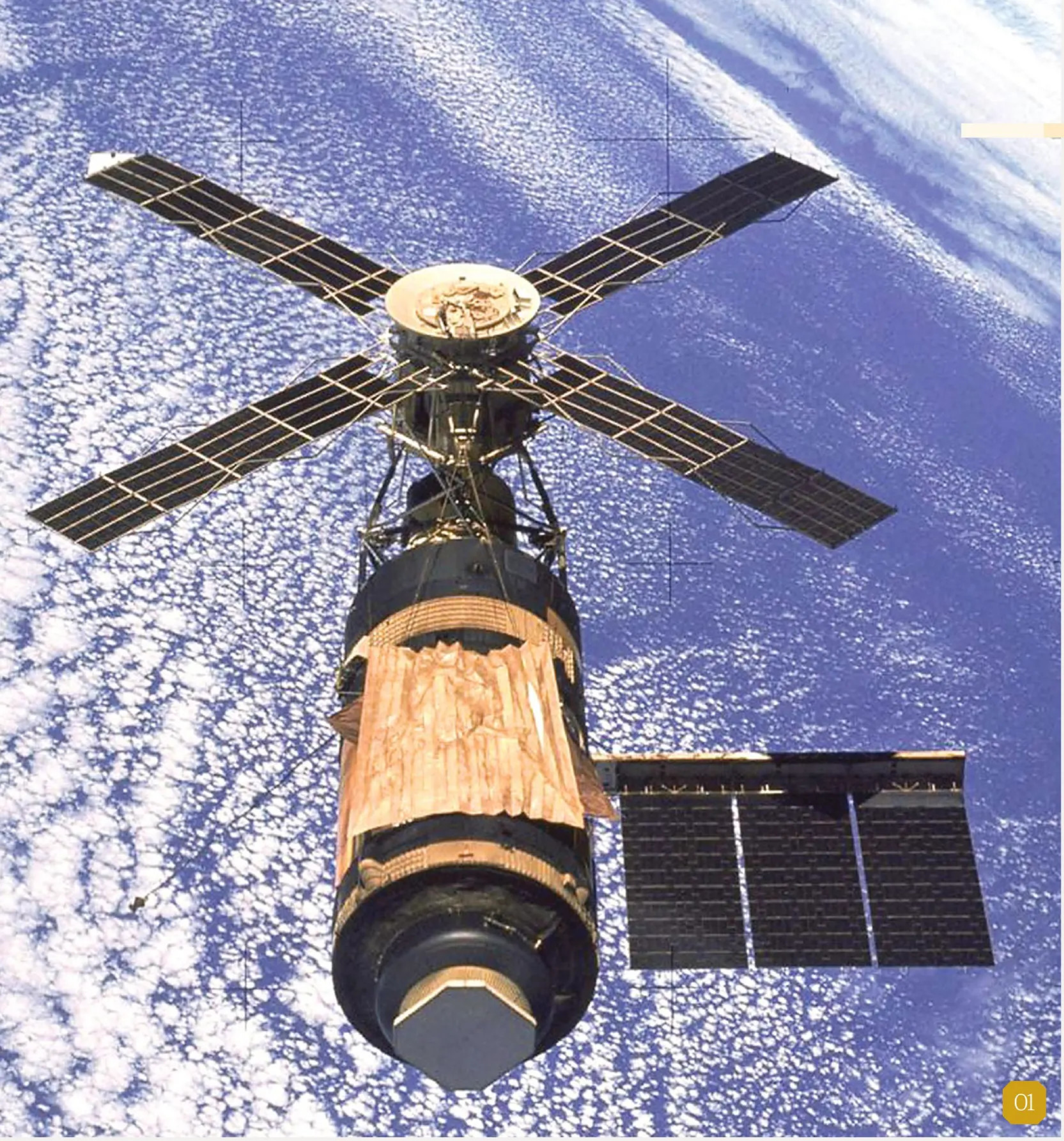
Skylab 3 astronaut Owen Garriott performs a spacewalk

Skylab was a surprisingly large station, comparable in liveable space to a three-bedroom house. It had a number of amenities that were tested for the first time and would become mainstays of future space stations Mir and the International Space Station, including a toilet and shower. After overcoming the initial disorientation of living in zero-gravity, all nine astronauts who stayed on Skylab reported no problems operating in a weightless environment. All their experiments were highly successful and, using the solar observatory attached to the station (the Apollo Telescope Mount), the astronauts performed the most detailed observations of the Sun at the time.

In total three different three-man crews visited the station, Skylab 2, 3 and 4, with the trips lasting 28, 59 and 84 days respectively. The last mission to the station departed on 8 February 1974. In anticipation of another crew visiting the station following their exit, the astronauts left behind supplies including food and water. The events that followed, however, meant that astronauts Gerald Carr, William Pogue and Edward Gibson would be the last residents on Skylab.

The original plan was for Skylab to remain in orbit for another ten or so years, with crews possibly being brought to the station by the Space Shuttle. However, in 1978 it was discovered that the Sun was entering a period of increased solar activity, which in turn would push Skylab lower in its orbit, culminating in an uncontrolled re-entry in 1979. NASA devised a plan to use a Space Shuttle to boost the station higher but, when the Space Shuttle programme was delayed until 1982, it became apparent that Skylab could not be saved.

The size of Skylab meant that it wouldn't entirely burn up in the



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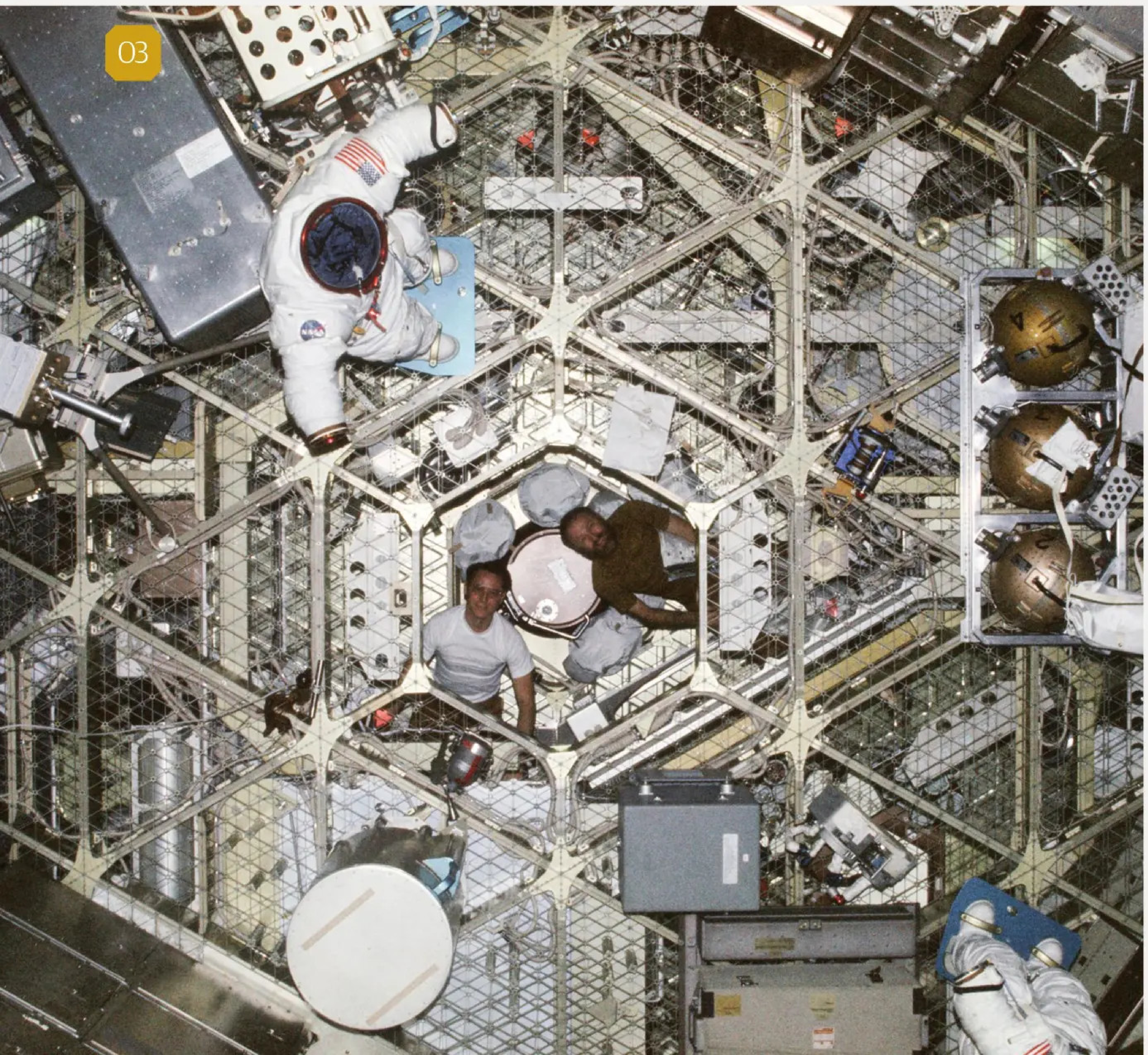

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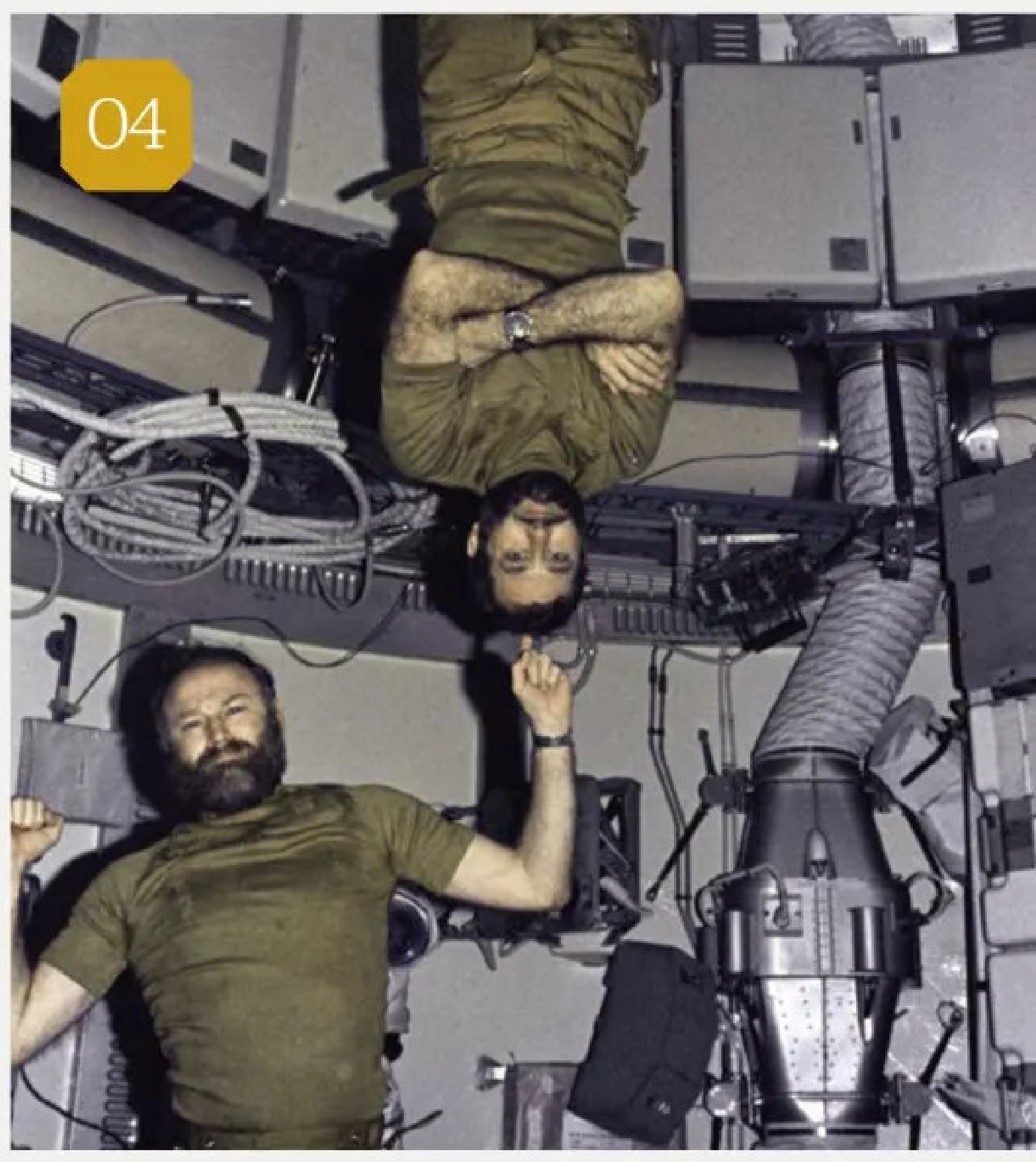
**1. Skylab**
Only one of Skylab's two solar panels managed to deploy successfully after launch.

**2. Launch**
Skylab launched on a modified Saturn V rocket in 1973.

**3. Spacious**
The interior of Skylab was surprisingly large.

**4. Zero-gravity**
Two Skylab astronauts demonstrate zero-gravity.

**5. Food**
Meals on Skylab were a step-up from previous space missions.



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atmosphere, and it was likely that debris would make it to the surface. In addition, ground control did not have complete control over the station, so they could not direct where the debris would land. Skylab moved into a state of freefall and, on 11 July 1979, it began to re-enter the atmosphere amid a media maelstrom.

As it descended the station burned up and broke apart, but parts of it managed to survive the harsh temperatures of re-entry. Initial reports said that it had fallen safely into the Indian Ocean away from populated areas. One community in Western Australia, however, disagreed. Residents in the Shire of Esperance were startled when a multitude of sonic booms could suddenly be heard in the sky as pieces of debris broke the sound barrier. Chunks of Skylab rained across Esperance, including an oxygen tank, but fortunately no one was harmed.

Esperance took it all on the chin, however, and there were several endearing stories to come out of the incident. Stan Thornton, a 17-year-old from the area, was alerted by his mother to a piece of Skylab debris in the family's garden. After learning that the *San Francisco Examiner* was offering $10,000 USD to anyone who could deliver a piece of Skylab debris to its office, Stan cooled down the debris, hopped on a plane to San Francisco with nothing more than a toothbrush and his wallet and was greeted by throngs of media who watched him claim his prize.

Esperance also jokingly fined NASA $400 for 'littering'. Despite several requests from the American public to pay it over the years, the fee remained unpaid until a persistent radio host arrived in Esperance in 2009 with a cheque for the full amount of money, donated by his listeners. Scott Barley of the Highway Radio in Barstow, California handed over the money to widespread applause as people remembered the event that put the Shire of Esperance firmly on the map.

Skylab's high-profile demise was testament to its massive significance in an age where space exploration was still riding the waves of the previous Apollo successes. It will forever be regarded as one of NASA's pioneering achievements, and it certainly paved the way for the current International Space Station, providing a large amount of key information and experimental evidence that will doubtless prove useful for future missions in decades to come.

## Inside Skylab

**Apollo Telescope Mount**
This solar observatory, manually operated by Skylab crews, was attached to the station before launch and imaged the Sun at a variety of wavelengths from ultraviolet to infrared

**Multiple Docking Adapter**
Two docking ports were provided to which the crew's spacecraft could dock with the station, although only one was ever used

**CSM**
The three crews to visit Skylab were all taken to the station by an Apollo Command and Service Module (CSM). These were nearly identical to those used on the Apollo missions

**Missing panel**
Although pictured here, this solar panel never actually deployed as intended. It was ripped off during launch by a faulty micrometeoroid shield

**Saturn workshop**
A number of pieces of equipment were stored here including a ring that astronauts ran around for exercise and biological tests

**Experiments**
A number of scientific and biological experiments were carried out, including solar observations and physical exercise

**Living quarters**
Astronauts each had a private sleeping area the size of a walk-in closet with a curtain, locker and sleeping bag. A dining table, shower and toilet were among other amenities

**Micrometeoroid shield**
Designed to protect the station from solar radiation, during launch one of these shields ripped off. The station reached scorching temperatures until the first crew deployed a makeshift parasol

**Dimensions**
Skylab was surprisingly roomy, with around 300 cubic metres (10,500 cubic feet) of liveable space

**Airlock module**
Ten spacewalks were performed on Skylab, totalling 42 hours. Astronauts entered and exited the station through this airlock

**Solar panels**
An early spacewalk was needed to unfold this side panel, while the main X-shaped solar panels also supplied power to the station

## Mission Profile

### Skylab space station

**Launch:** 14 May 1973
**Mass:** 77,000kg (170,000lb)
**Altitude:** 435km (270 miles)
**Days in orbit:** 2,249
**Days occupied:** 171
**Number of orbits:** 34,981
**Distance travelled:** 1.4 billion km (890 million miles)
**Re-entry:** 11 July 1979

СОЮЗ
APOLLO
Bert Winthrop

A commemorative painting of the Russian and American crews of Apollo-Soyuz by Bert Winthrop of Rockwell International Space Division, 1975

# Astronauts, cosmonauts and a new era

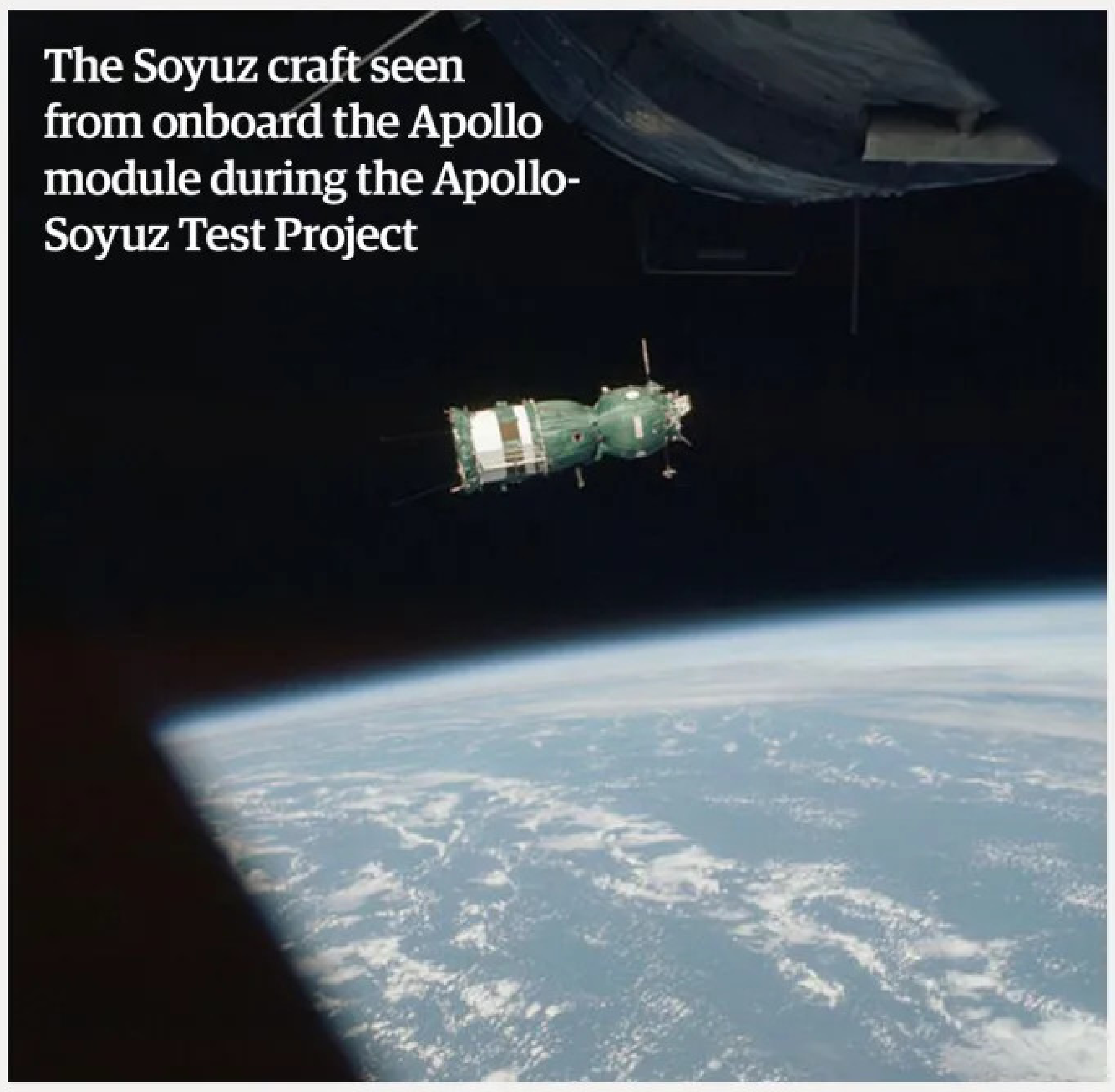
The Apollo-Soyuz Test Project, tangible evidence of détente, opened a new era of space cooperation between the US and the Soviet Union

At the height of the Cold War, a half-century of mistrust, intrigue, and animosity between the superpowers of the Soviet Union and the United States, virtually any form of cooperation was unthinkable. The nations had come to the brink of nuclear war during the Cuban Missile Crisis, and the US had been embroiled in the protracted Vietnam War.

However, by the early 1970s, the highly-charged political tensions began to ease. An opportunity for rapprochement emerged, oddly enough, on a frontier where international rivalry had once been most heated – the exploration of space. The Americans had succeeded in placing a man on the Moon with Apollo 11 in 1969, while the Soviets had committed to their Salyut space station programme in 1970.

Both governments decided to pursue a political path of détente, the “art of relations between nations”. In the autumn of 1970, NASA and its counterpart, the Soviet Academy of Sciences, exchanged communications concerning a joint mission, and two-way governmental support hastened the initiative. In April 1972, the nations signed the Agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes. Embedded in the document was the pledge to launch the Apollo-Soyuz Test Project by 1975.

Still, there were bridges to be built, literally and figuratively. Each programme had experienced triumph and tragedy, and their approaches to space exploration differed. Soviet cosmonauts were dependent on automation and likely to abort missions when a system failed. American astronauts were highly trained in the operation of their spacecraft, and NASA had chosen to rely on human decision-making capacity to successfully conduct missions. The Apollo spacecraft was not numbered, although it has sometimes been referred to as Apollo 18, resulting in confusion with the lunar mission that was renumbered during the winding down of the Apollo programme. The Soviet spacecraft was designated Soyuz 19.



The Soyuz craft seen from onboard the Apollo module during the Apollo-Soyuz Test Project

One operational hurdle involved the Soviet use of an oxygen-nitrogen atmosphere in crew areas, while the Americans functioned in an atmosphere of pure oxygen. Logistically, the development of a suitable docking chamber was problematic. Distance and communication barriers complicated face-to-face collaboration. Ultimately, the Androgynous Peripheral Attach System (APAS) was jointly developed and constructed in the United States.

The mission itself involved docking the Apollo command/service module with the Soyuz 7K-TM spacecraft. The crews would also exchange positions, allowing them to work inside the other's vehicle. Prior to launch on 15 July 1975, the American crewmen, Commander Thomas Stafford, Command Module Pilot Vance D Brand, and Docking Module Pilot Donald 'Deke' Slayton, were allowed to inspect the Soyuz spacecraft, as well as the crew training and launch sites.

The Apollo-Soyuz flight was Stafford's fourth. An Air Force general, he had flown in Gemini 6 and Gemini 9 and commanded the Apollo 10 flight. Brand, a Marine Corps officer, later flew aboard three Space Shuttle missions. Slayton, an Air Force officer, was one of the original Mercury 7 astronauts chosen in 1959; however, an irregular heartbeat had kept him grounded. After receiving clearance to fly in the mid-1970s, Slayton, age 51, became the oldest man in space until 77-year-old John Glenn flew aboard the Space Shuttle Discovery in 1998.

Commander Alexey Leonov, an Air Force officer, led the two-man Soyuz crew. Leonov had become the first man to walk in space on 18 March 1965, leaving his crew compartment during the Voskhod 2 mission for 12 minutes. Soviet flight engineer Valeri Kubasov was a civilian who had previously flown in Soyuz 6 and later commanded the Soyuz 36 flight to the Salyut 6 space station.

Soyuz 19 launched at 8:20am Eastern Daylight Time, from the Balkonur Cosmodrome in Kazakhstan. The Apollo spacecraft lifted off seven and a half hours later from Launch Complex 39B at Kennedy Space Center, Florida. For two days the spacecraft manoeuvred into docking position, painstakingly making the necessary adjustments. While a worldwide television audience watched, Apollo-Soyuz successfully docked at midday on 17 July.

Three hours later, the hatches were opened. Stafford and Leonov shook hands in a defining moment in the history of space exploration. The crews received affirmative calls from Soviet Premier Leonid Brezhnev and US President Richard Nixon, exchanged gifts, including seeds for trees to be planted in each country and national flags, and ate together before parting.

On 18 July, the crews exchanged positions as Brand worked with Kubasov aboard Soyuz 19 and Leonov joined Stafford and Slayton in the Apollo ship. The space travellers conducted a televised tour of the vehicles, ate lunch together, and performed scientific experiments. In the afternoon, Leonov and Stafford moved into Soyuz 19, while Kubasov and Brand met Slayton aboard the Apollo spacecraft. More gifts and handshakes were exchanged prior to the last hatch closing. During their time together, the crewmen had spoken in each other's languages. Leonov laughed that Stafford's distinctive southwestern drawl resulted in three languages being spoken, English, Russian, and 'Oklahomski'.

The spacecraft parted early on 19 July, and the Apollo craft blocked the sun to create an artificial eclipse, allowing the cosmonauts to photograph the sun's corona. A second docking took place, and then the final departure occurred at mid-morning. Soyuz 19 landed safely on Earth two days later, less than seven miles from its expected location near Baikonur Cosmodrome.

The Apollo splashdown occurred in the Pacific Ocean on the afternoon of 24 July, and the astronauts were taken aboard the amphibious assault ship USS New Orleans. During the splashdown, the crewmen were exposed to nitrogen tetroxide fumes through an inadvertently open air intake; they were hospitalised for two weeks in Hawaii.

The Apollo-Soyuz Test Project was a resounding success, opening the door for future US-Soviet cooperation in space, including the Shuttle-Mir program that saw astronauts living side-by-side with cosmonauts in space for nearly 1,000 days, beginning in 1994 in preparation for the International Space Station programme, begun in 1998 and expected to continue through 2028.

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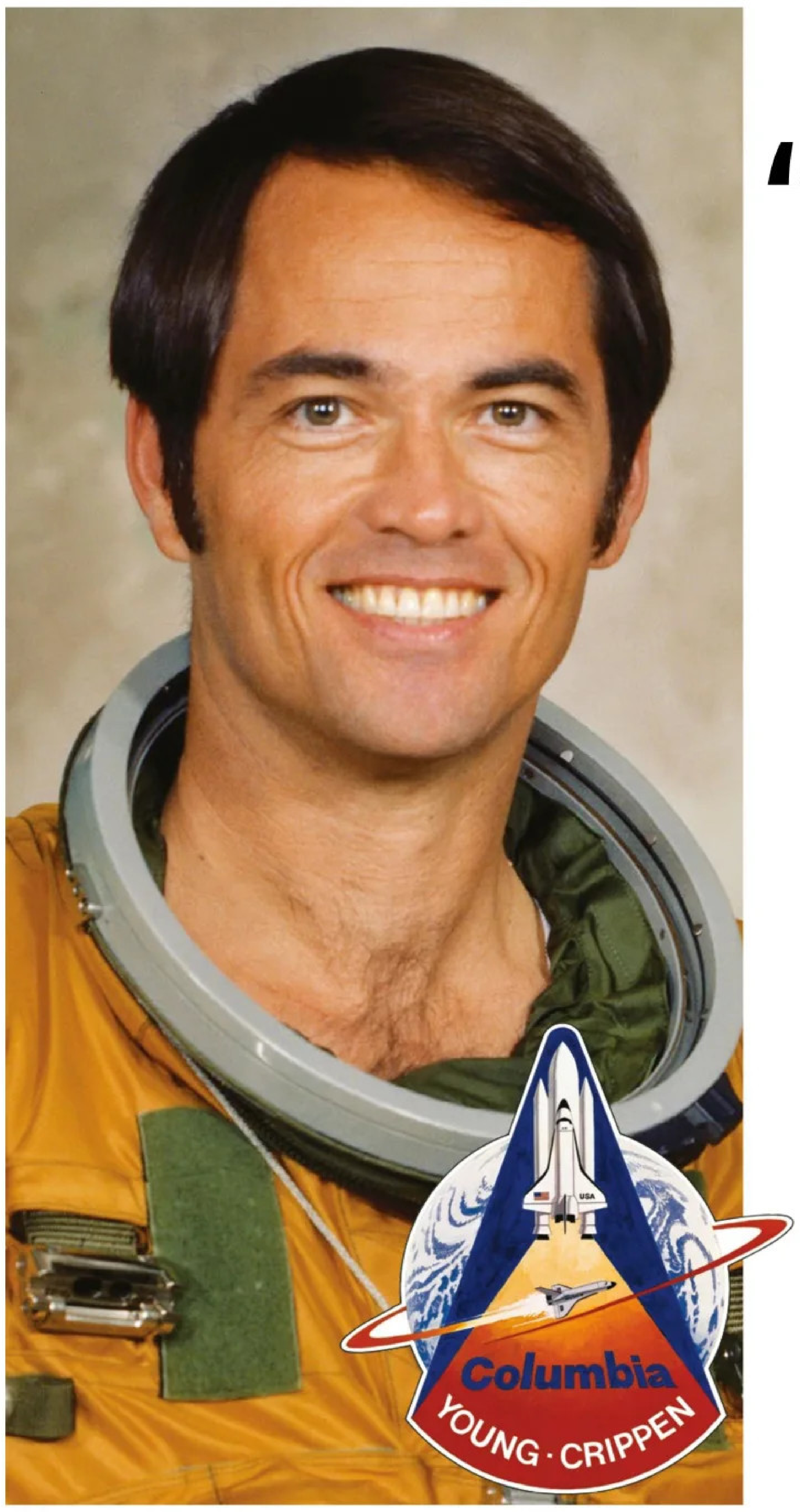
# Flying the first Space Shuttle: "Beyond my wildest dreams"

Robert Crippen, the first-ever Shuttle pilot, talks about his maiden flight and the Space Shuttle programme



'Bob' was 28 when he first became an astronaut

**How did it feel to finally get your first flight on the first Space Shuttle mission, STS-1?**

Well, that was fantastic. When I was asked if I'd like to fly the first one I was turning handsprings. I couldn't imagine that they would let a rookie go on the first flight but that was beyond my wildest dreams.

**You had quite a long wait for your first mission, how did you find that?**

Well, when we were transferred over to NASA early in 1969 we were still doing the lunar flights. Deke Slayton, who was in charge of all the astronauts, told us that he didn't have any lots for us to fly. Back then we had a lot of work to do supporting some of these programmes like Apollo and Skylab, but the probability was that there wasn't going to be anything to fly until this thing they were working on called the Space Shuttle was done, and it probably wouldn't be until around 1980. I didn't anticipate flying in those early days but I had lots of fun working on those programmes.

**What was it like on that first flight?**

True excitement. I was selected as an astronaut when I was 28 years old and there I was finally at 43 about to fly the first flight [laughs]. It was something I'd worked long and hard on and initially we had quite a few technical problems, mostly associated with the main engines and our thermal protection system, and so John Young and I had been selected about three years before that flight ever took off. The fact it all finally came together was really exciting. We scrubbed the first attempt on 10 April 1981 due to a computer glitch, and when we went back out on 12 April I thought there was a high probability we would scrub again. In fact, I even dozed off during the countdown, and it was only when the counting got inside of a minute that I really got excited and I turned to John and said, 'I think we might really do it', and sure enough we did. It was great doing that first Space Shuttle flight, it will always stick in my mind. The best part, as my buddy John Young said, was the part between take-off and landing, but it was all fantastic.

**How did steering the Space Shuttle compare to manoeuvring a jet?**

It was quite manoeuvrable. It had a computer modelling system so you were actually flying it through the computers and when you have a flight control system like that you can tweak it to be however you want, and since all of us astronauts at that time had been flying high performance small jet aeroplanes we tweaked it to make it pretty responsive. It flew a nice course as a glider, and even though it doesn't look all that streamlined because of the way you're flying it, it responded great. It was a fine flying machine.

**What was it like to witness the end of the Space Race between the US and USSR in 1975?**

It was kind of funny having been a soldier of the Cold War to then be involved with Russia at that time in 1975 [the Apollo-Soyuz Test Project]. I can recall on May Day [1 May] standing beside Lenin's Tomb with Brezhnev watching the May Day Parade and I thought, 'Boy, how did we get here?' But you know working with the cosmonauts was great, we were the first ones to ever go to their launch site and some pilots the world over became very good friends with some of the cosmonauts.

**What were your highlights from your other three Space Shuttle missions?**

Well, all of them were great. That first one will always stand out in my mind, but to be commander on the subsequent three flights and have great crews to fly with was something I thoroughly enjoyed. The mission that we probably had the biggest trauma on was STS-41C when we were going up to capture a satellite [Solar Max] that had a problem with its attitude control system. Unfortunately, like what quite often happens with technical stuff, it wasn't built exactly according to the drawings we had. George D Nelson was going to go out in a free flying Manned Maneuvering Unit [propulsion system] and capture it with a little device that he had, but it turned out the little device wouldn't

> "I even dozed off during the countdown, and it was only when the counting got inside of a minute that I really began to get excited"

## BIOGRAPHY

**Robert Laurel Crippen**

Born on 11 September 1937 in Beaumont, Texas, Crippen joined NASA in 1969. He was given his first flight as a pilot on Columbia on 12 April 1981. He later served as commander on three Challenger missions before becoming Director of the Shuttle programme and then Director of the Kennedy Space Center before leaving NASA in 1995.

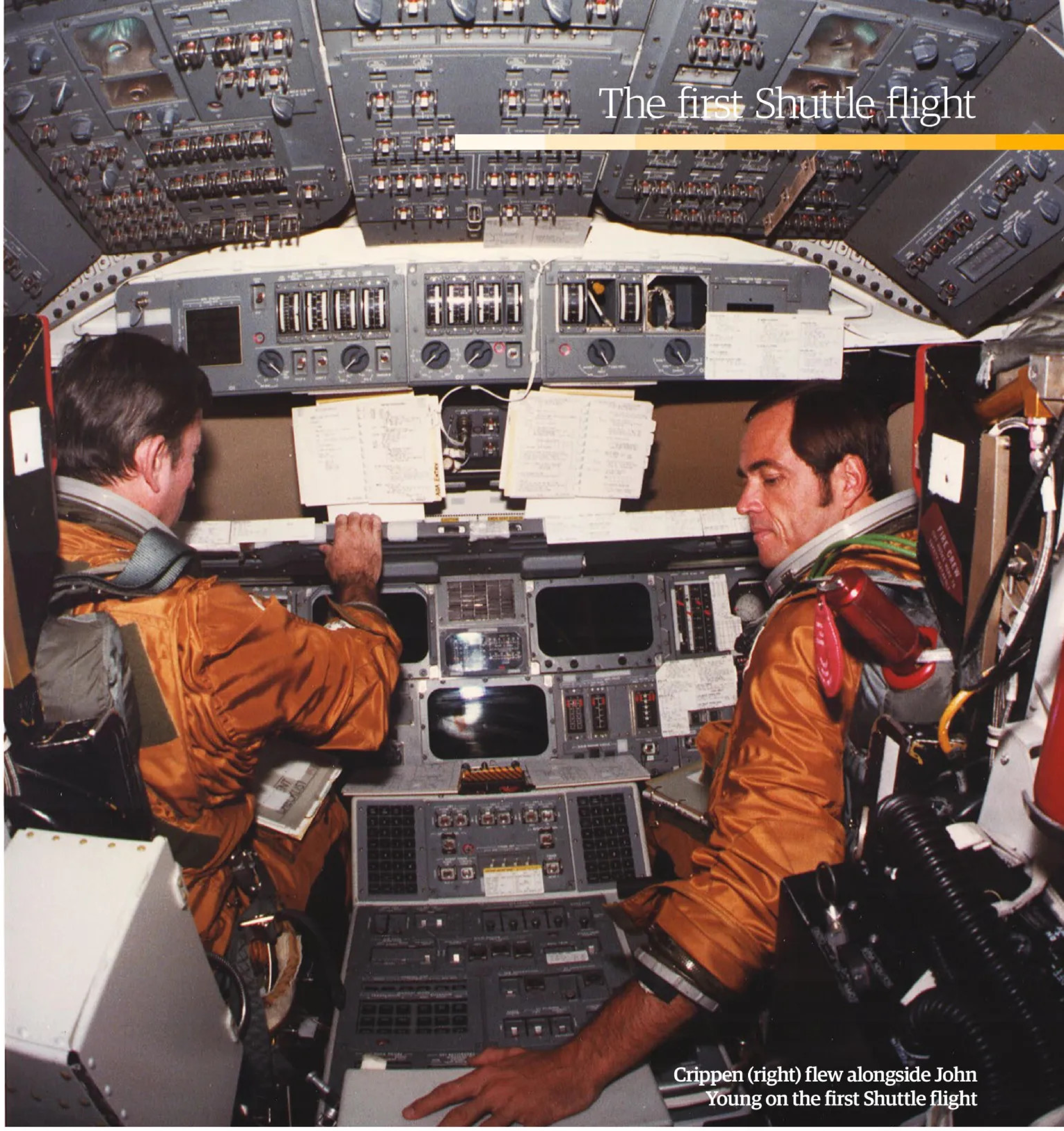
latch on and the satellite bounced around a while and started tumbling. We tried to catch it but that didn't work, so we finally backed off and the ground managed to get it rotating slowly and we came back in the next day and did capture it. That was quite a bit of trauma, but we were glad to be able to do it and we did repair and re-deploy it.

**Did you ever train to do a spacewalk [Extra-vehicular activity]?**
I did train for an EVA on the first flight because it was critical with the large payload bay doors that we had that they were closed before re-entry. You would not survive with the doors partially open. I did train to go outside by myself with this big wrench to pull the doors closed and latch them shut, but fortunately I didn't have to go and do that.

**Did you have any heroes in your time at NASA?**
One of the people I admired the most, mainly because of the way he ran things and was straightforward, was Deke Slayton. I really admired Deke, he was one of the best bosses I ever had. But there were lots of great guys, and John Young was sort of a hero to everybody. He had flown four times in space including working on the Moon on Apollo 16 and I trained with him for three years so John will always be near and dear to me.

**You flew on both Challenger and Columbia, so it must have been especially poignant when those two vehicles and their crews were lost…**
It was devastating when we lost Challenger [on 28 January 1986]. I was preparing to fly a fifth flight at that time and I had a lot of good friends on board the vehicle including the commander Dick Scobee, who had been the pilot on my third flight [STS-41C], so that was a terrible time. That was when I ended up getting out of the astronaut programme to go into the Space Shuttle programme and get it flying again. That was probably one of the most difficult things I ever did in my life, working through all the issues and getting the vehicle back flying but it was also one of the most rewarding. I was retired when we lost Columbia [on 1 February 2003], and my daughter who taught astronauts how to fly the Space Shuttle was in mission control and she gave me a call at home and told me they'd lost contact with Columbia. In retrospect, even though it was a different kind of an accident, a lot of the management issues that we had encountered back when we lost the Challenger were still there, so it was disappointing to see us forget some of those lessons we learned. But they did get it back flying again, it took them a while but both of those vehicles were near and dear to me, and the people as well.

**What were your thoughts on the retirement of the Space Shuttle?**
I thought it was totally inappropriate to retire the Shuttle until we had another capability to get Americans into space that was ours. The Shuttle could have continued flying, but I also wanted to see us get beyond Low Earth Orbit and that meant we needed another kind of vehicle. Unfortunately, the way the budgets were, there was no way we could continue flying the Shuttle and build a new vehicle. But now we're kind of back on track, although I'm still not clear where America is going with her human space flight programme.


Crippen (right) flew alongside John Young on the first Shuttle flight

Crippen was commander for three Space Shuttle Challenger missions – STS-7, STS-41C and STS-41G – in the 1980s

STS-1 and STS-2 were the only Shuttle missions to ever use a white rocket booster

# Space Shuttle Challenger

## Mismanagement and incompetence caused one of the worst accidents in the history of spaceflight

"Uh oh." Those were the chilling final words of pilot Michael Smith, and the final transmission sent from the Space Shuttle Challenger. It will never be known what thoughts were going through Smith's head as he uttered those two words. Because a split second later, the vehicle exploded, leading to the deaths of all seven astronauts on board the Shuttle. How and why this happened is a complex story laden with mismanagement, misfortune and, ultimately, tragedy.

The story of Challenger begins long before its final flight on 28 January 1986. In fact, you can essentially trace it back to the start of the Space Shuttle programme. When the Space Shuttle was first dreamed up in the 1970s, it was unlike anything in space exploration that had come before. Previously, spacecraft had taken the form of capsules launched to space on a rocket, and then parachuted back to Earth at the end of the mission. This was tried, tested, and, for the most part, safe. But space travel was and remains expensive, so in an effort to reduce costs (and also capabilities), NASA envisioned having a space plane that could fly regularly to orbit and back. While the finished product wasn't quite the space planes of *2001: A Space Odyssey*, it was still mightily impressive, albeit without reducing costs by as much as hoped due to the high cost of refurbishment after each mission.

With this increased capability came the prospect that space travel might not just be the reserve of professional astronauts any more. The Space Shuttle could seat seven people, but not all were needed to operate the vehicle; two could be 'payload specialists', people of other professions such as scientists, or even more general members of the public, such as writers, who could now travel to space.

This Challenger mission, STS-51-L, was to be the 25th Space Shuttle mission since the first in April 1981. This launch rate itself was remarkable, but also showed a confidence in the vehicle, with several launches every year. As such, in 1984, President Ronald Reagan announced the Teacher in Space Project (TISP), which would start taking teachers on Space Shuttle missions as payload specialists. This was a completely new area for NASA, and indeed any space agency.

11,000 teachers applied for the coveted first slot, which would be aboard STS-51-L. After being whittled down to ten, one candidate emerged as the frontrunner thanks partly to her unbounded enthusiasm: Christa McAuliffe, a social studies teacher from Concord High School, New Hampshire. McAuliffe was scheduled to do a large amount of public outreach during her two weeks in orbit, including two 15-minute lessons to 2 million schoolchildren in the US, among other activities.

"I'm still kind of floating," she said at a press event after her selection. "I don't know when I'll come down to Earth."

With McAuliffe picked, preparation for the mission was well under way. At a time when public interest in the Space Shuttle programme was dwindling, NASA hoped she would re-invigorate a public infatuation

USA
NASA
Challenger
United States

## What the mission would have done

During its seven days in space, Challenger had a number of goals it would have completed had the launch been successful.

Its main goal was to launch the second Tracking and Data Relay Satellite (TDRS-B), used by the US government and other agencies to communicate with things like satellites, and later the International Space Station.

A small satellite on board, the Spartan Halley spacecraft, would have flown free from the Shuttle for two days to observe Halley's Comet as it made its closest approach to the Sun.

On the second day, Christa McAuliffe would have begun the first teacher in space video taping, with further live telecasts planned for the fourth day.

One member of the crew, Ronald McNair, was even planning to play the saxophone in space, performing a piece of music he worked on with composer Jean Michel Jarre for his album *Rendez-Vous*.

The seventh day would have been Challenger's triumphant return to Earth, after 144 hours and 34 minutes in space. Sadly, that never came to pass.

## FACTS

**73** Seconds after launch, Challenger exploded.

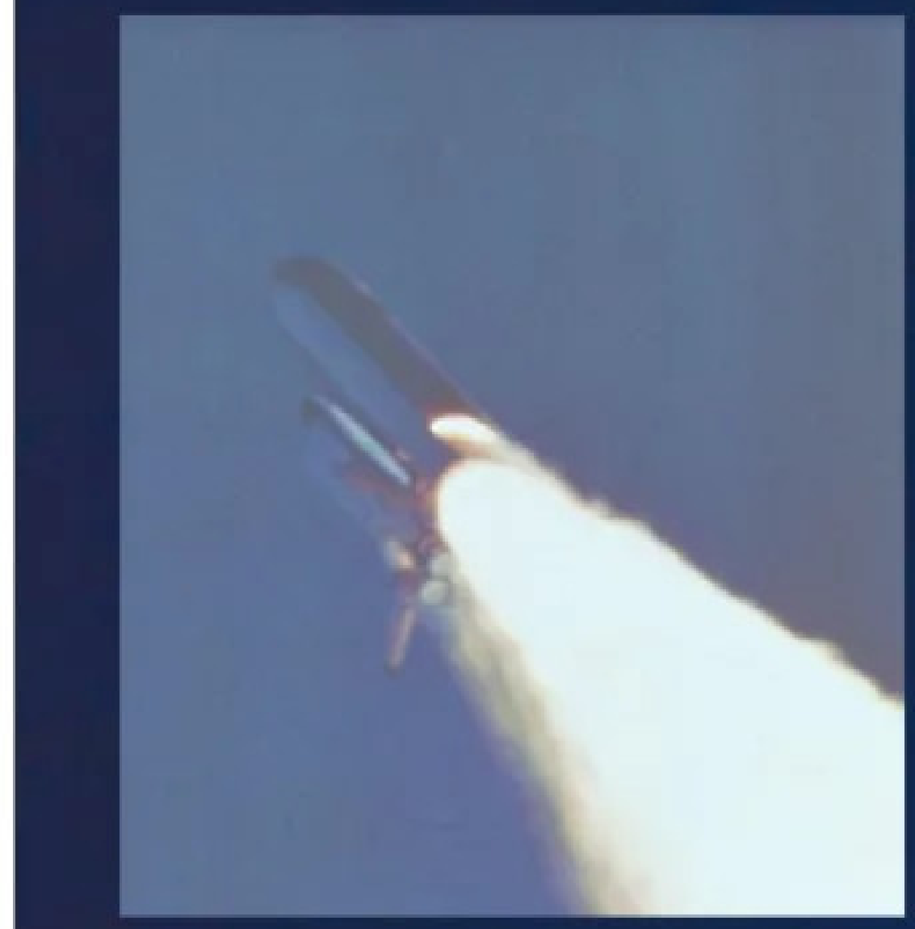
**9** Successful flights of the Challenger Space Shuttle.

**7** Number of people lost in the accident

**995 orbits** Challenger completed prior to this mission

**25.8 million miles** Cumulative distance travelled by Challenger on previous missions

**121,778KG** Weight of Challenger on its final flight



**In this image above, the plume that led to the explosion can be seen developing**

> "The launch feeds, live on TV, showed this plume at 58 seconds after launch, although it's unlikely many knew its significance"

with the costly vehicle. Together with proving that it was safe and reliable, some have said that NASA had a case of "go fever" at the time of the Challenger mission in question. That is, they wanted to launch their Space Shuttles as quickly and as often as possible. It is perhaps for this reason, then, that problems with the launch of Challenger arose.

When the Space Shuttle was first being developed in the 1970s, an early potential problem was discovered. To launch, the Shuttle was first attached to a main tank, with two Solid Rocket Boosters (SRBs) either side. Each of these was made of seven sections, six of which were joined together and sealed with rubber 'O-rings', circular rings measuring 11.6 metres in diameter.

Utah-based manufacturing company Morton Thiokol was behind the construction of the SRBs, but in early testing they found a potential problem with the O-rings. In some specific tests, the metal of the SRB could bend and open, allowing hot gas to escape through the seal made by the O-rings. If serious, this could result in something called 'burnthrough', where hot gases escape and, ultimately, cause a structural failure of the SRBs. In other words, an explosion. That the seal of the O-rings could open was known, but the seriousness of the problem was not fully realised.

The Space Shuttle itself was also lacking a proper launch abort system. For previous manned rockets with capsules, this system composed of a spike with thrusters attached to the top of the rocket. In the case of an emergency, the capsule could be carried to safety before the rocket exploded. NASA had never had a need for this system on any of its previous manned flights.

On the Space Shuttle, though, the entire crew were housed inside a cabin, much like a plane. With seven crew across two decks, there was no way to eject everyone in the case of a catastrophic failure. There had been some talk in development of creating a detachable crew cabin, but this proved too difficult, most notably with adding too much mass to the entire vehicle.

This meant there was no feasible way to get a crew to safety during a Shuttle launch. Following the Challenger disaster, things changed. The crew were provided with parachutes and, in the event of an emergency after launch, the pilot would attempt to get the Space Shuttle into a controlled glide. Each crew member would then jump out via a hatch with explosive bolts, shimmying down a pole to make sure they missed the wing when they jumped. This launch abort system was never used, and at any rate, the SRBs could not be stopped once they were ignited. This meant that to get the Space Shuttle into such a glide, the pilot would have to wait for the SRBs to expend all their fuel after about two minutes. Thus, this method would not have saved the crew of Challenger, who likely died upon impact with the Atlantic Ocean.

All of this leads us to the events on the fateful day of Tuesday 28 January. This mission had huge public attention, notably because of McAuliffe on board; it's estimated that 17 per cent of Americans watched it live, and 85 per cent knew of the accident within an hour after it occurred.

Leading up to the launch, STS-51-L was already dogged by delays. Scheduled to launch on 22 January, it had been pushed back to the following day, and then the next, due to delays with the previous mission, Space Shuttle Columbia on STS-61-C. Further delays arose because of bad weather in Dakar, Senegal, where the Space Shuttle could land in an emergency mid-flight. These factors pushed the flight back to 28 January.

All Space Shuttles launched from the famous Kennedy Space Center Launch Complex 39 at Cape Canaveral in Florida. The site is useful for its proximity to the equator (giving launches a bigger speed boost from Earth's rotation), and also having an east-facing coast over an ocean. This allows parts (such as SRBs) to be discarded in the ocean after launch. But Florida is also known for its changeable weather, and on the morning of the launch, temperatures dropped to below freezing at -2.2 degrees Celsius. The previous coldest launch had been 12 degrees Celsius.

Engineers at Morton Thiokol warned NASA that the rubber seals, the O-rings, wouldn't seal properly at temperatures this low. One, Rob Ebeling, was particularly forthcoming in his views. NASA, however, was staunchly opposed to a delay; after all, the Space Shuttle was already grossly behind schedule, and they were getting impatient.

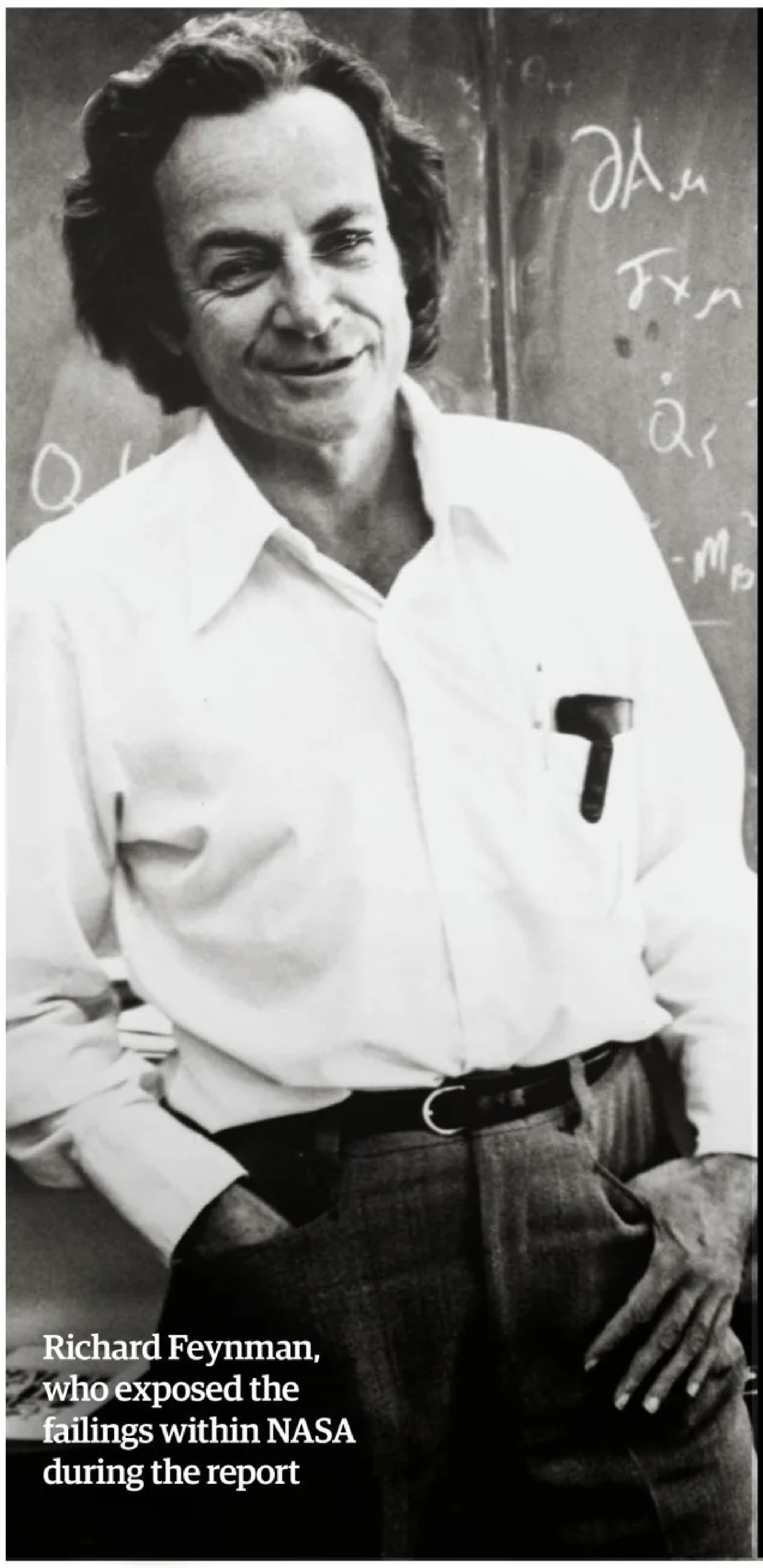
An astonishing exchange then occurred. Thiokol's management had told NASA they should delay the launch but, in a conference call, NASA's George Hardy, manager of the SRB project, said: "I am appalled. I am appalled by your recommendation." This was recollected many years later by Roger Boisjoly, another engineer at Thiokol, as reported by NPR. Another Shuttle programme manager, Lawrence Mulloy, added: "My God, Thiokol. When do you want me to launch, next April?"

Incredibly, despite these concerns, NASA pressed ahead with the launch. Then, for reasons unknown, Thiokol's management reversed their original view and said the launch should go ahead.

Ebeling was particularly shocked. He told his wife Darlene that night before the launch, "It's going to blow up," reported NPR. Later, in an interview in 2016, he said, heartbreakingly: "I think that was one of the mistakes that God made. He shouldn't have picked me for the job. But next time I talk to him, I'm gonna ask him, 'Why me? You picked a loser.'"

So, in the morning, launch preparations went ahead. A huge amount of ice had built up on the rocket, raising more concerns about the SRBs. Launch was delayed by an hour but, as the ice appeared to be melting, the decision was made to go ahead. At 11.38am EST, Challenger launched.

Just two seconds after launching, things started to go wrong. Almost immediately, the O-rings failed, but a piece of solid fuel created a temporary seal. Amazingly, this may have been the only thing to



Richard Feynman, who exposed the failings within NASA during the report

## Rogers Commission Report

Almost as infamous as the Challenger disaster itself were the circumstances surrounding the investigation into why it occurred. Under the orders of President Ronald Reagan, a commission was set up to determine the cause of the disaster. Among its many members were some high-profile names, including Neil Armstrong and Sally Ride. One name would later attract the most attention, though: Richard Feynman, an American theoretical physicist.

The investigation came to the conclusion that the accident was caused by the failure of the O-rings in creating a seal in the SRBs due to a flawed design. "The Commission has concluded that neither Thiokol nor NASA responded adequately to internal warnings about the faulty seal design," the report would ultimately conclude.

Feynman, though, led his own investigation, delving into the inner workings of NASA itself. What he found was a gross disconnect between the engineers and management.

One of his most startling finds was the expected failure rate of the Space Shuttle. NASA management told him there was a one in 100,000 chance of a catastrophic malfunction, but it soon became clear this number was all but plucked from the air. When he asked the engineers to anonymously estimate their own odds of failure, their numbers were mostly between one in 50 and one in 200. Most famously, Feynman performed a makeshift experiment on O-rings during a televised hearing, putting one in a cup of ice.

His style was not liked by other members, and his findings were confined to a minority report within the main report.

prevent the Shuttle exploding immediately on the launch pad. Challenger climbed higher into the sky, and the launch appeared to be going as planned. "Liftoff of the 25th Space Shuttle mission," NASA television commentator Hugh Harris said.

But 36 seconds after launching, Challenger experienced a huge blast of wind, a wind shear, pushing it sideways. The on-board computers compensated for this motion, but in doing so, dislodged the piece of solid rocket fuel. This wind shear is thought to have been the largest ever experienced on a Shuttle launch and, tragically, had it not occurred, there's every chance the mission may have succeeded.

That, sadly, was not the case. Having throttled down the engines while passing through the wind shear, Challenger now throttled up again as it continued its climb towards space, at about 51 seconds after launch. At 58 seconds, a flame flickered into life in a joint on the right-hand SRB, where one of the O-rings had failed. In half a second, this developed into a visible plume.

The launch feeds, live on TV, showed this plume at 58 seconds after launch, although it's unlikely many knew its significance. The flame began to burn onto the SRB itself, burning through the joint that attached it to the main tank. Those in mission control were equally unaware. At 68 seconds, the capsule communicator for the mission – astronaut Dick Covey – gave a standard call to increase the power of the Shuttle's main engines. "Go at throttle up," he said. "Roger, go at throttle up," Commander Dick Scobee on board Challenger responded.

The result was almost instantaneous. At 72 seconds, the flame burned through the struts holding the right SRB to the main tank. It pivoted around its upper strut, hitting the main tank. At 73 seconds after launch, disaster struck.

In a split second, the external tank split. There was not an explosion as such, but more of a violent breakup and fire. The resultant force split Challenger into pieces, while the SRBs, more sturdily built, flew away from the explosion in uncontrolled flight. By 78 seconds, the air was filled with a huge cloud of fire, smoke, and propellant. Pieces of the Shuttle were flung in all directions. The iconic image of the Challenger explosion is one few will forget.

Ice on the Shuttle on the morning of the launch, showing how cold it was

One cause for contention, though, regards when the astronauts actually died. At the time, NASA's official line was that they were knocked unconscious or killed by the blast, and remained so until their cabin plunged into the ocean, killing them all instantly. However some experts, and an exhaustive story from reporter Dennis E Powell in the *Miami Herald's Tropic* magazine, have suggested that the crew survived and were conscious through the whole event until the ocean impact. With no means of escape, they would have been trapped inside the crew cabin for two minutes and 45 seconds as it plummeted to the sea, eventually impacting at 333 kilometres per hour and killing all seven.

Later reconnaissance done at the bottom of the Atlantic Ocean, where Challenger's cabin came to rest, revealed that some of the astronauts had turned on their oxygen masks, suggesting they had indeed survived the initial fire and breakup. It's unlikely we'll ever be sure exactly when they died. Salvage crews brought up the remains of the astronauts; those that could be identified were given to their families, and the rest buried at Arlington National Cemetery in Virginia in a monument to the crew.

Immediately after the accident, engineers and mission controllers had the grim task of poring through the data, to find out what went wrong. It wouldn't be until the Rogers Commission Report that the fault – that of the O-rings – became widely known. In fact, early reports said that destruction charges on the external tank had been detonated by mistake – although the salvage operation proved this not to be the case.

President Ronald Reagan gave an address from the Oval Office after the disaster. "We've grown used to wonders in this century," he said. "It's hard to dazzle us. But for 25 years the United States space programme has been doing just that. We've grown used to the idea of space, and, perhaps we forget that we've only just begun. We're still pioneers. They, the members of the Challenger crew, were pioneers."

The Space Shuttle would not fly again until 29 September 1988, when the Discovery launched on a "Return to Flight" mission. The programme would continue successfully until 2003, when another disaster – that of Columbia – again rocked NASA.

Aside from the Shuttle being grounded, NASA also had issues with contractors who wanted their satellites to be launched on the Shuttle. Some asked to use other rockets in NASA's fleet, such as the Titan rocket. NASA's policy towards the media, too, has changed drastically since. Members of the press were denied information in the early days after the accident; today, the agency is much more open towards the media.

The Challenger disaster was a dark day in the history of spaceflight. It remains a shadow over NASA, and perhaps plays some part in why the agency is so cautious with its human space flight endeavours today. The Space Shuttle programme was ended in July 2011, but the crew of Challenger will live long in the memory.

## The aftermath of Challenger

The Challenger disaster rocked NASA to its core. The Space Shuttle programme was grounded for 32 months, during which the Rogers Commission Report took place. For the agency, it was a time to re-evaluate the Shuttle program.

The SRBs were redesigned to prevent such a problem happening again. The joints were strengthened by adding an additional O-ring, while much better monitoring of temperature was initiated to ensure no materials were affected by changeable conditions.

From a public-relations point of view, the Challenger disaster put NASA's plans to make space travel achievable for civilians on hold, with Christa McAuliffe dying in the accident. Originally, it had been planned to have a journalist follow McAuliffe a year later, and then an artist. Ultimately, anyone could have flown.

According to *Smithsonian Magazine*, a NASA-appointed task force in 1983 remarked that, "It is desirable for NASA to fly observers on the shuttle for the purpose of adding to the public's understanding of space flight." One NASA spokesperson even thought they'd have 3 million applicants if they opened the opportunity to the public, with a lottery on the cards as a way to decide who got to fly. Even Big Bird, of *Sesame Street* fame, was considered by NASA as an option, alongside writers who could pen wonderful prose about the experience.

In fact, two weeks before the Challenger disaster, more than 1,700 journalists had applied to go on a subsequent Space Shuttle mission. Following the accident, no journalist ever flew.

The backup to McAuliffe, Barbara Morgan, did eventually fly on a Space Shuttle, Endeavour, in 2007. But the Challenger disaster ended the dream that the Shuttle might be the spacecraft for the people. Nowadays, we look to private companies like SpaceX and Blue Origin for that same inspiration.

"With no means of escape, they would have been trapped inside the crew cabin for two minutes and 45 seconds as it plummeted to the sea"

## The crew

### Dick Scobee

46-year-old Francis Richard 'Dick' Scobee was the commander of the Challenger mission. Born on 19 May 1939 in Washington, he joined the US Air Force in 1957, and the NASA Astronaut Corps in 1978.

### Michael Smith

The pilot on the Shuttle was Michael J Smith, who died at the age of 40. He was born in Beaufort, North Carolina, on 30 April 1945. He served in Vietnam for the US Navy, and joined NASA in May 1980.

### Ellison Onizuka

Mission specialist Ellison Shoji Onizuka was to be the first Asian American to go into space, and the first of Japanese ancestry. He was born on 24 June 1946 in Kealakekua, Hawaii, and served in the USAF. He died aged 39.

### Judith Resnik

36-year-old mission specialist Judith Resnik was to become the second American woman in space after Sally Ride. Born in Akron, Ohio, on 5 April 1949, she was a biomedical engineer and systems engineer before joining NASA in 1978.

### Ronald McNair

Born in South Carolina on 21 October 1950, mission specialist Robert Evander McNair, 35, was a physicist before he joined NASA in 1978. He flew on one mission prior to the disaster, in 1984, also on Challenger.

### Gregory Jarvis

Payload specialist Gregory Bruce Jarvis was born on 24 August 1944 in Detroit, Michigan. Jarvis was an engineer, despite a four-year stint in the US Air Force, and was selected as a candidate payload specialist in July 1984. He died at 41.

### Christa McAuliffe

Payload specialist Sharon Christa McAuliffe was born on 2 September 1948. She was to be the first teacher in space as part of NASA's flagship Teacher in Space Project (TISP), selected in 1985. She died at the age of 37.

The Hubble Space Telescope in orbit

# Saving the Hubble Space Telescope

## The critical servicing missions that repaired one of NASA's most important instruments

NASA's Hubble Space Telescope was launched on 24 April 1990 after years of development, but straight from the off there was an almost embarrassing malfunction. The telescope's primary mirror had been ground to an incorrect shape, leaving its images out of focus.

The problem would not be rectified until December 1993 when astronauts on Space Shuttle Endeavour corrected the error during the STS-61 mission. You can see the mission taking place in the fantastic image on this page, where astronauts Story Musgrave and Jeffrey Hoffman are in the process of installing a set of specialised lenses to correct the flaw.

In January 1994 the mission was declared a success and Hubble was fully operational. A further four servicing missions were carried out on the telescope to correct minor problems and install new features, with the final mission taking place in May 2009 on the STS-125 mission aboard Space Shuttle Atlantis.

Thanks to these servicing missions, Hubble has become one of NASA's greatest-ever achievements, sending home fascinating images and information from across the far reaches of the universe. Despite the early blip it's now regarded as an unequivocal success, and continues to return cutting-edge science regularly.

USA

# Space Shuttle Columbia

## How seven astronauts lost their lives on Columbia in a mission that was doomed from the start

Inside mission control, there are three words you do not want to hear: "Lock the doors". Because when these are uttered, the mission has been a failure, and the painstaking task of recovering all data must begin. The last time these words were said for a manned mission on US soil was in 2003 – and they are words no one in mission control ever wants to hear again.

Space Shuttle Columbia broke up on its return to Earth after a two-week stay in space on 1 February 2003, killing all seven of its crew instantly. Alongside the Challenger disaster in 1986, it is the biggest loss of life in a single spaceflight tragedy. As shocking footage captured the break-up of Columbia on its return to Earth, the months and years that followed would reveal some awful conclusions.

Columbia was NASA's flagship Space Shuttle. When the Shuttle program was first designed in the Seventies, Columbia was selected as the name of the first vehicle that would fly to space (although a test vehicle named Enterprise had flown in the sky previously), a name shared by both Captain Robert Gray's ship that explored the world, and the Apollo 11 Command Module that journeyed to the Moon. This flight, STS-107, was to be its 28th mission, but it had been dogged by delays. The Space Shuttle had originally been intended as an all-purpose orbital vehicle, used to conduct science in the microgravity environment of space and take people of all walks of life on the trip of a lifetime – such as teacher Christa McAuliffe, who died in the Challenger accident.

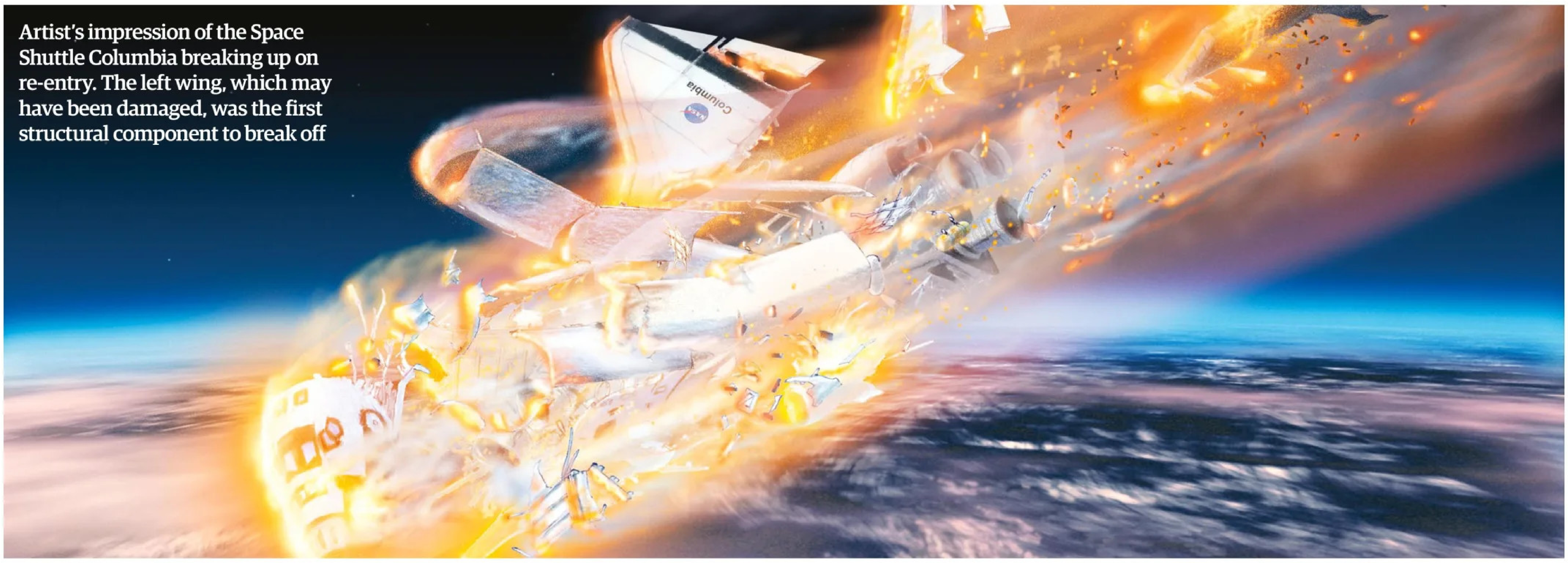
By 1998, however, a new purpose for the Space Shuttle had been devised. NASA, together with its Russian counterpart Roscosmos, had decided to build a grand space station, the likes of which had never been seen before: the International Space Station (ISS). The Space Shuttle was given the job of ferrying most of the American components, or modules, for this huge $100 billion orbiting outpost, the size of a football field.

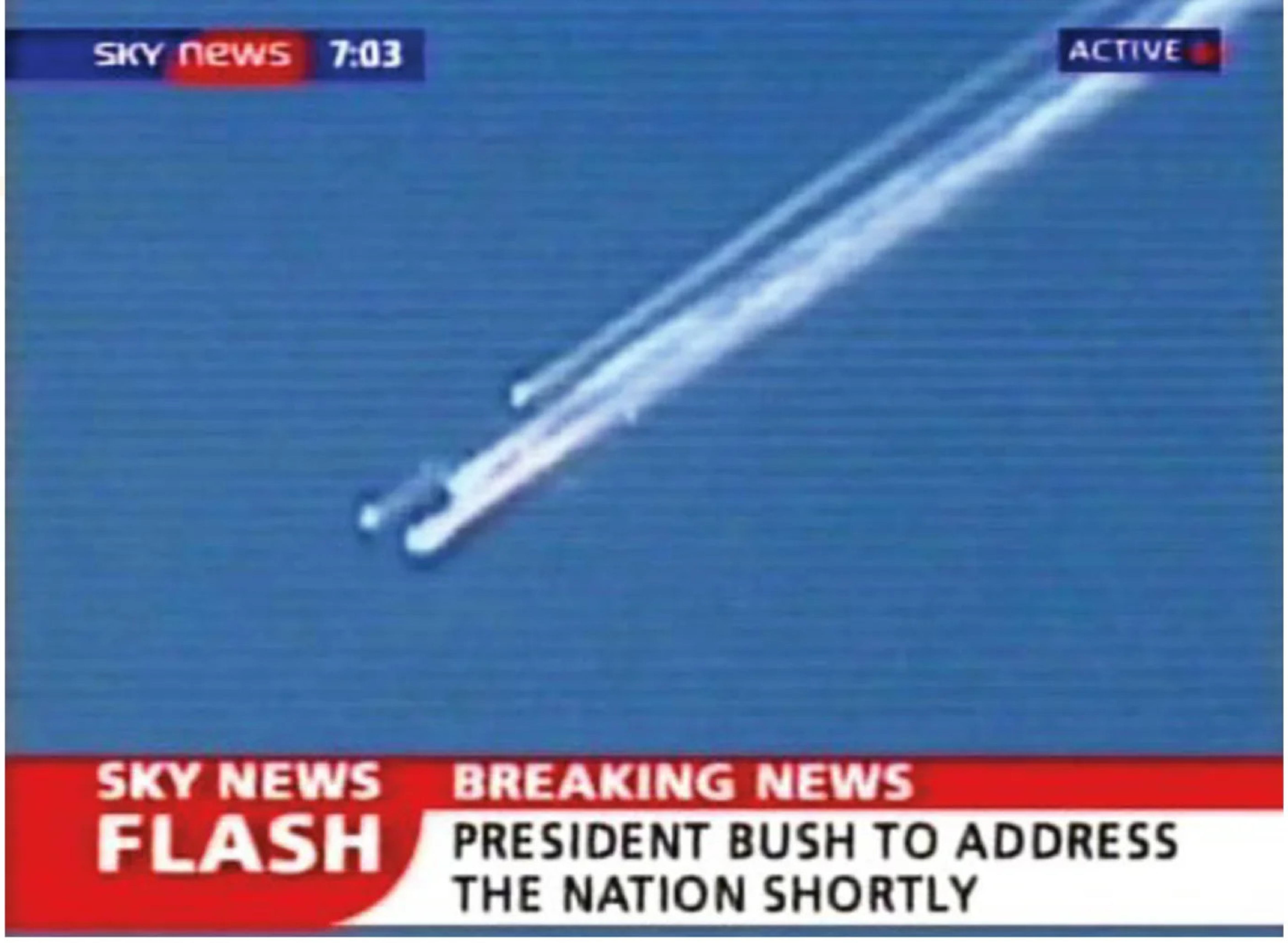
As such, science missions began to play second fiddle, and the large majority of Space Shuttle flights became either assembly missions – taking new modules to the ISS – or supply missions for the station, which began having crews stay for long durations in November 2000. These missions did not perform much – or any – useful science.

The scientific community were in uproar, fearing that they were missing a prime opportunity with the Shuttle to perform groundbreaking science in orbit. So, with a lot of pressure on NASA to justify spending $4 billion a year on the Shuttle program, STS-107 was selected to be a return of sorts to scientific missions.

On board, it would carry a new state-of-the-art research laboratory in its cargo bay, called SPACEHAB, which would be used to conduct 80 science experiments in orbit over about two weeks. To accomplish all these tasks, the team were split into two teams – red and blue – so that they could work around the clock, 24 hours a day, to complete the huge number of jobs allocated to them.

> "The months and years that followed would reveal some shocking conclusions"


Artist's impression of the Space Shuttle Columbia breaking up on re-entry. The left wing, which may have been damaged, was the first structural component to break off



"If we didn't work 24 hours a day we'd be giving up eight hours of sleep time that could otherwise be used for science," STS-107 pilot William McCool said in an interview with the BBC prior to launch. "So the intent is to pack each minute of the 24 hours that we're on orbit with science."

Truth be told, these experiments probably weren't designed to engage the public; they were not the most exciting selections. One, for example, was an examination of dust above the Middle East. Another would extract oils from rose and rice flowers, to be used in perfume research. Aside from some experiments to observe weightlessness on a few animals, like spiders, there wasn't a huge amount to grab anyone's attention. But the mission was what the scientific community wanted, and after 16 days in orbit, it was declared a success.

However, the nature of the mission, being scientific and not part of the ISS Assembly phase, meant that it was continually pushed back in favour of what were deemed the more important missions. STS-107 was first planned to launch in May 2000, but it was forced to wait all the way until January 2003, with more than a dozen other missions taking place in between. For the crew of this mission, some of who were flying for the first time, it was a lengthy wait.

Finally, the date was announced: 16 January 2003. The crew prepared for this mission, the 113th flight of a Shuttle, just like any other. Columbia was rolled out to the launch pad at the Kennedy Space Center in Florida aboard the giant crawler that's so iconic of these launches. Everything looked good. At 10.39am local time, it took off.

Prior to this launch, an issue had started to arise with the Space Shuttle and the large orange external tank that fed it fuel. This tank was covered in thermal insulation foam, which stopped ice forming when it was full of its fuel: liquid hydrogen and oxygen. If you look at a picture of the Space Shuttle attached to this tank, you'll note that it is attached by struts. Next to these were Bipod Foam Ramps, designed to reduce the aerodynamic stresses on the struts. But these small ramps were exposed, and on several flights prior to STS-107, parts of them had been observed falling off during launch. The idea that one of these might pose a significant problem to the Shuttle, though, was not seriously considered. And so, STS-107 took off. But 82 seconds into the flight, the left Bipod Foam Ramp broke, and a chunk of this foam slammed into the left wing of the Space Shuttle.

Although not picked up originally, high-resolution camera shots two hours after launch showed this happening. The launch continued unabated, with the Shuttle not experiencing any temperatures remotely near the intense heat of re-entry when going up and out of Earth's atmosphere.

The problem, though, was far more serious than anyone realised. In order to cope with the extreme heat of re-entry, the Space Shuttle had an advanced thermal protection system (TPS) on its underside, black tiles that could handle the 1,650 degrees Celsius (3,000 Fahrenheit) heat. On its top were white tiles, used to insulate the Space Shuttle.

A shower of particles from the foam impact is just visible on the left wing in this photo
KSC ICE & Debris Team

Columbia
United States

## FACTS

**82** Seconds into flight that fatal piece of foam hit Columbia's vital left wing

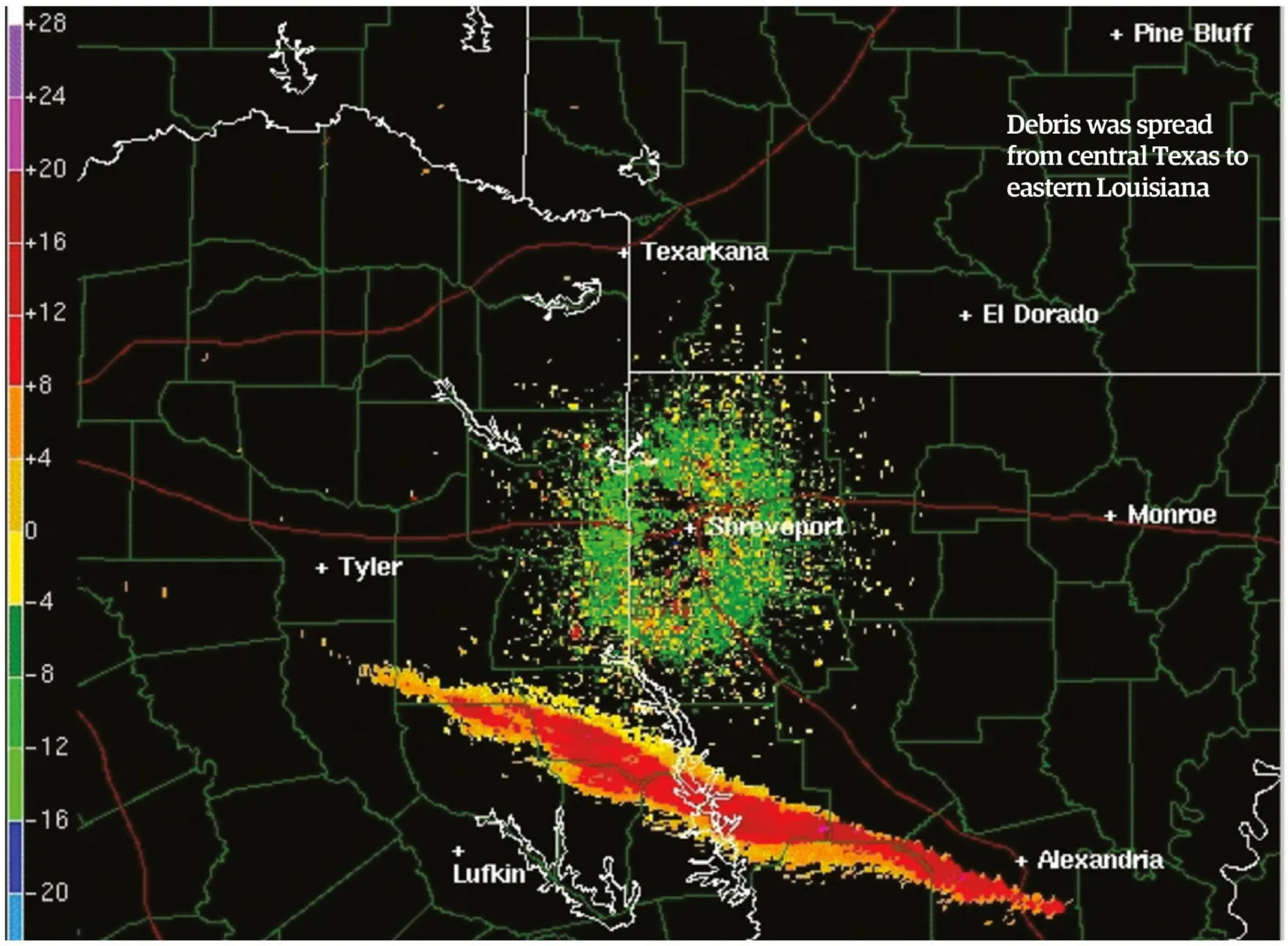
**255** orbits successfully completed in the mission

**15 days, 22 hours** Time spent in orbit

**6.6 million** Miles travelled by Columbia while in orbit

**29** Number of months until a Space Shuttle flew again

**12,738** Speed in miles per hour at time of break-up



Debris was spread from central Texas to eastern Louisiana

But on the leading edge of the wing was an ultra-strong material, reinforced carbon-carbon (RCC); it was also on the nose of the Shuttle, to deal with the intense aerodynamic forces of flight. Built to last, no one imagine that these could be severely damaged by a piece of falling foam. Following the accident, investigators re-enacted the foam strike to see if such an occurrence was possible. Taking the wing of another shuttle, they fired pieces of foam at it at the speeds and angle from the Columbia launch. The results were without doubt – the foam could easily have punched a hole in the wing.

At the time of the Columbia flight though, this was not known. So unbeknownst to the crew while they carried out their mission in space, they were essentially aboard a ticking time-bomb. With a hole punched through the wing, the Shuttle would not survive re-entry as hot gases flew into it.

While the seriousness of this problem was not fully realised, even if it had been, there was another problem. Although not widely discussed at the time, there was a rather ghastly scenario. If a hole had been punctured in the wing of the Shuttle, there was almost certainly no way the crew could be saved, barring an ambitious rescue mission with another Shuttle, which had never been tried before.

"You know, there is nothing we can do about damage to the TPS," Jon Harpold, Director of Mission Operations, told Flight Director Wayne Hale, the latter revealed in a blog post online. "If it has been damaged it's probably better not to know. I think the crew would rather not know. Don't you think it would be better for them to have a happy, successful flight and die unexpectedly during entry than to stay on orbit, knowing that there was nothing to be done, until the air ran out?"

The grim scenario mission controllers were left with, therefore, was to continue with the mission and hope for the best. Touchdown was scheduled for 9.16am EST on 1 February 2003.

> "Aside from a few worried faces, the thought of losing the Shuttle was not on many minds"

When the time came for re-entry, aside from a few worried faces, the thought of losing the Shuttle was not crossing many minds. And at first, things looked on track. Columbia was passing over the US on its way to a landing in Florida, flying on autopilot. While the landing itself was not making headlines anywhere, as this was supposed to be a routine flight, Shuttle enthusiasts watching the re-entry began to notice something going wrong. At a height of more than 210,000 feet, observers reported seeing chunks of the Shuttle fall off.

Inside mission control though, the problems were not yet obvious. During re-entry, which was past the point of no return to put the Shuttle back in orbit, the first indication of an issue was a dramatic drop in pressure of the left main landing gear. A faulty tyre itself was a problem for a runway landing, with a serious risk of the Space Shuttle crash landing and flipping.

Soon, though, temperature readings on the left side of the vehicle began to go haywire. Mission control continued to assess the situation, trying to find out if the various anomalous readings were related. Columbia's last transmission came from Commander Rick Husband; "Roger, ah," he said, before being cut off. Although breaks in communication were normal for re-entry, this was lasting much longer

## The Columbia investigation

Following the accident, NASA convened a special panel to investigate the cause. Called the Columbia Accident Investigation Board (CAIB), it involved various figures from the military and NASA, in addition to many academic researchers, who pored through the available data to work out the cause of the accident, and what could be done to prevent something similar happening. The report was released on 26 August 2003, six months after the accident.

Some of the main findings from the report concerned when the crew were killed. The first, rather obviously, was the moment of depressurisation, as the orbiter was breaking up and the astronauts were exposed to the thin atmosphere outside. At this moment, some astronauts were not wearing suitable equipment like their helmets, which meant death was likely swift. "Although circulatory systems functioned for a brief time, the crew could not have regained consciousness upon descent to lower altitudes due to the effects of the depressurisation," the report noted.

It also found that the crew were not wearing proper restraints, which meant that as the orbiter began to lose control, the crew would have been thrown about. Their fate was sealed when they slammed into the ground; the parachutes relied on manual activation, something the report said should be changed.

The findings brought about a change in spaceflight safety, with a variety of new safety measures introduced for future Shuttle flights – including getting rid of the foam ramp that struck the wing of STS-107. In total, the CAIB made 29 recommendations to NASA.

"It is the team's expectation that readers will approach the report with the respect and integrity that the subject and the crew of Columbia deserve," the report concludes. It is free to read online via a quick Google search.

HUSBAND
MCCOOL
STS-107
IN MEMORY OF THE CREW OF
UNITED STATES SPACE SHUTTLE COLUMBIA
1 FEBRUARY 2003

Michael Anderson
Payload commander
Ilan Ramon
Payload specialist
William
McCool
Pilot
Rick Husband
Commander
Kalpana Chawla
Mission specialist
David Brown
Mission specialist
Laurel Clark
Mission specialist

## Could Columbia's crew have been saved?

We know that Space Shuttle Columbia itself, with the hole punctured in its wing, would not have survived re-entry. Even if the astronauts had spacesuits to use for spacewalks on board – which they didn't – it's unlikely they could have fixed the problem.

But there was one other, much more ambitious option. The Shuttle could not be saved, but the crew maybe could have been, thanks to another Shuttle being almost ready to launch.

Atlantis was scheduled to launch from Cape Canaveral on 1 March 2003, just six weeks after Columbia. On board the orbiting Shuttle, the crew had enough supplies to keep them alive for 30 days, beyond which they would suffer from asphyxiation.

While the launch of Atlantis was six weeks away, there was a chance that it could be sped up to just four weeks. This would have involved streamlining all the launch processes, like software checks, with technicians working around the clock. Such a mission would have been unprecedented, but not impossible.

Had the problem been properly identified by the second day of STS-107, preparations could have begun. With Columbia operating on severely reduced capabilities, Atlantis could have launched towards the end of that 30-day window. It would then have had to approach Columbia at right angles to keep the Space Shuttles close without their tails touching.

What would have happened next would have been drama of the highest order. Without spacesuits, and no way of docking the two vehicles, astronauts would have to be ferried to and from the two Shuttles. Atlantis would have been operating with a smaller crew of just four so that it could have fit all seven from Columbia on board, albeit tightly packed with 11 for the return.

Two astronauts from Atlantis would then perform a spacewalk over to Columbia, carrying two extra spacesuits with them. On each return trip, they would take members of the Columbia crew. But preparing to don a spacesuit and enter the vacuum of space takes hours; the entire procedure would have taken 48 hours before Atlantis attempted the return to Earth. Columbia, meanwhile, would have been programmed to burn itself up, unmanned, in Earth's atmosphere.

Of course, this mission never came to fruition. And had it ever been seriously considered, it would have posed a new dilemma. Would NASA have sent four more astronauts to space, knowing the problem with the foam had not been resolved and that they could lose 11 people, rather than seven?

than expected – beyond a minute. Incredibly, those in Mission control were still not clear on the situation as debris started raining down along an area 300 miles (480 kilometres) long, from East Texas into Louisiana. In total, more than 2,000 pieces of debris were recovered. Pieces smashed into roofs and onto farms, but thankfully no one was injured. Horrifyingly, some people reported finding human remains, including a heart, a skull, arms and feet.

"There was a hand, and a foot, then a leg from the knee down," Norwood Deputy Faron Howell told the *Telegraph* in an interview in 2003. "One of my men found a human heart. The biggest piece was a torso, the upper bit with the chest ripped in half. We think it was all from one astronaut… It was mangled real bad. You couldn't even tell if it was a man or a woman," he said.

Mission control continued in vain to communicate with the crew of Columbia. "Columbia, Houston, UHF comm check," the communicator Charles Hobaugh repeated over and over. But the worst had happened. Columbia had disintegrated. Its crew had likely been killed almost instantly by the depressurisation. The flight director, Leroy Cain, gave the command everyone was dreading.

"Lock the doors."

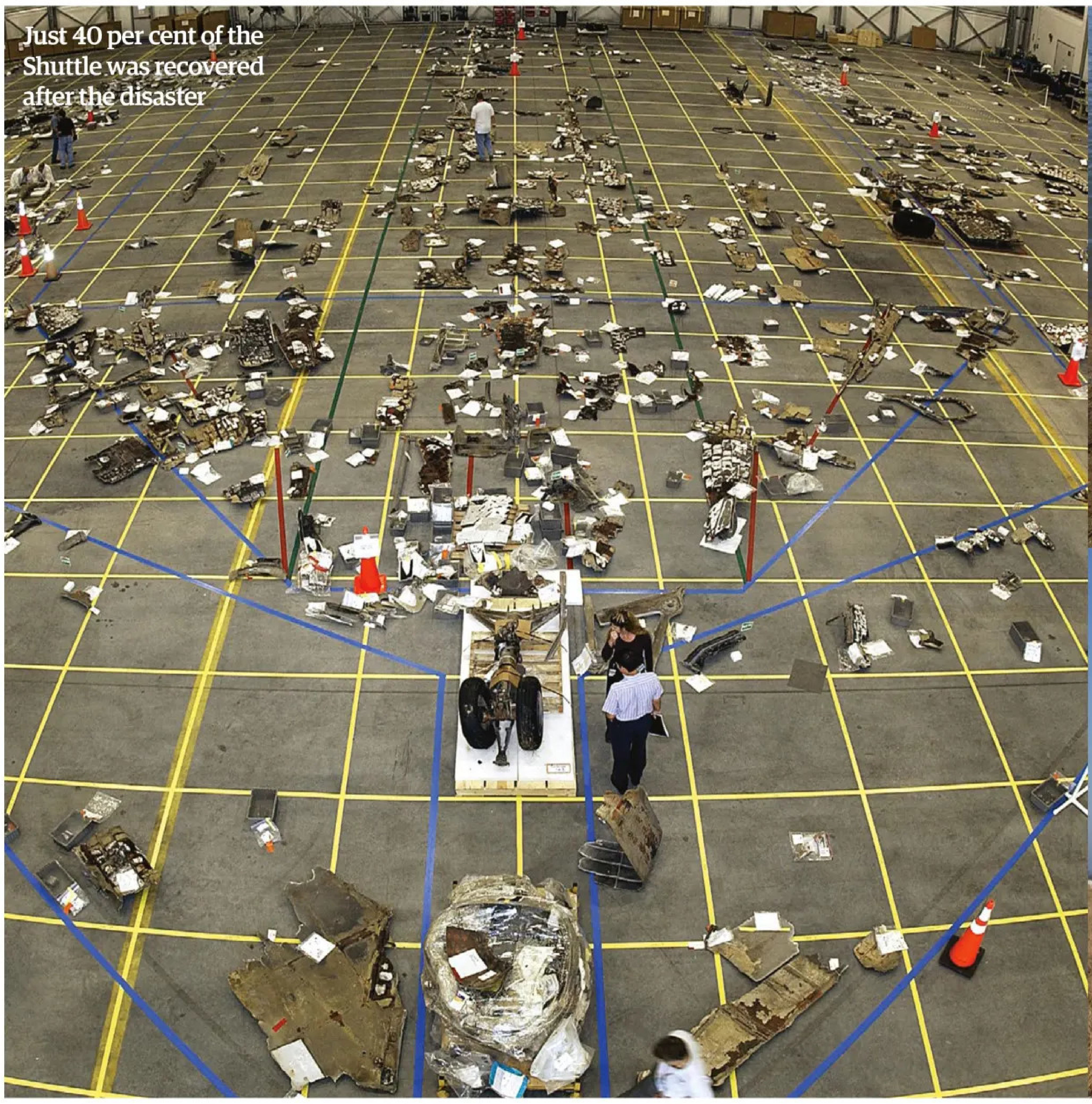
As mentioned earlier, this phrase means that everyone in mission control had to collect all of the data they had. No outside communication was allowed. Grief counsellors were brought in to calm people. The investigation had begun.

Unlike the crew of Challenger, who may have survived more than two minutes after the launch explosion, Columbia's crew were unlikely to have suffered for long. The resulting investigation concluded that the astronauts were probably aware of the problem for only 41 seconds, and when the break-up of the Shuttle began they would have lost consciousness almost instantly.

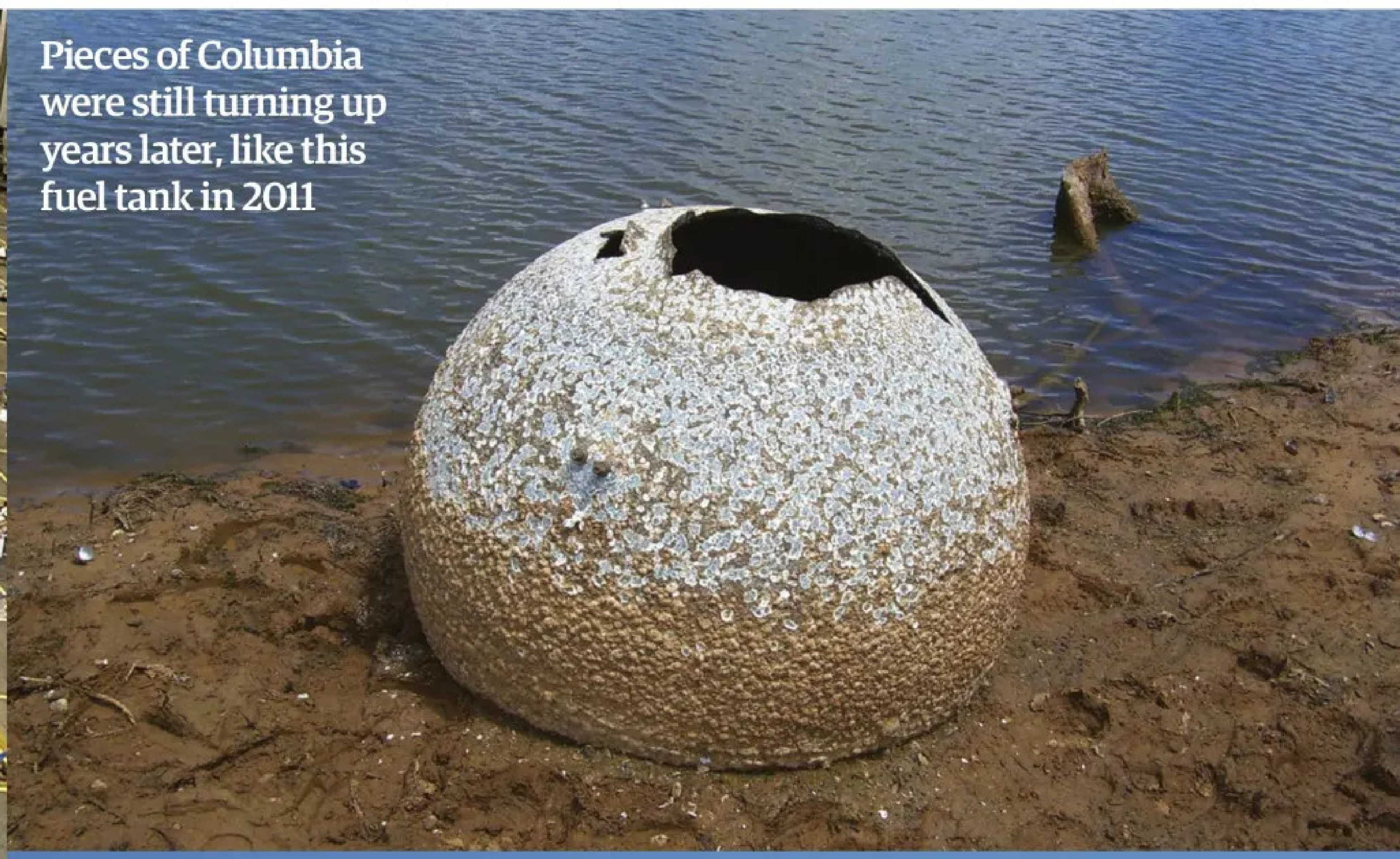
One consequence of the Columbia accident was that the foam ramp that had broken off and struck the Shuttle's wing was found to be not absolutely necessary for launch, so to prevent any foam strikes like this in future, it was scrapped. Thankfully, no more serious events occurred.

In the aftermath, it was also decided that no Shuttle could ever launch again without a valid rescue plan. So for every launch after Columbia's final flight, a back-up Shuttle (with the designation STS-3XX) was ready and waiting to perform a rescue mission, if required – that is, aside from the last shuttle mission in 2011, STS-135, which would have used

> "The Columbia disaster remains NASA's last loss of humans during a spaceflight mission"



Just 40 per cent of the Shuttle was recovered after the disaster



Pieces of Columbia were still turning up years later, like this fuel tank in 2011

Firefighting teams walk shoulder to shoulder through fields outside Corsicana in north Texas

Russian Soyuz spacecraft instead in the event of an emergency. But fortunately, no contingency mission was ever needed.

The Columbia disaster remains NASA's last loss of human life during a spaceflight mission. Numerous memorials have since sprung up around the world and beyond, including the landing site of the Spirit rover on Mars.

Columbia, though, was markedly different from the Challenger accident. On the latter, the issues were known prior to launch, and engineers had attempted to halt the ill-fated launch before it went ahead, but to no avail. On Columbia, that same level of mismanagement was not so apparent – not many had expected the foam debris to be capable of such a serious incident. Sadly, this belief was false.

Following the Columbia mission, there were just 22 more Shuttle missions – across orbiters Atlantis, Endeavour and Discovery – before the fleet was retired, with NASA shifting its focus from low-Earth orbit to missions beyond, such as back to the Moon and Mars. Columbia marked one of NASA's darkest days, and brought to an end an ambitious programme that never really reached its full potential in the years it was active.

Nonetheless, every single crew member throughout the Shuttle programme flew on missions they believed would better mankind, and propel us further and further towards the stars. The Columbia crew were no exception.

## Columbia's first fatalities

The loss of seven crew on a single flight was devastating. But you might be surprised to learn these were not the only tragedies associated with the Space Shuttle Columbia.

In 1981, five technicians were setting up the Shuttle for a ground test. They were performing a routine procedure, where nitrogen was used to purge the engines of the Shuttle of oxygen, so that no spark could accidentally start a fire. The Shuttle operated fine on the ground full of nitrogen, so tests could be carried out.

Nitrogen, though, can be deadly if inhaled directly. And, on 19 March 1981, five technicians incorrectly thought they had the all clear to enter the Shuttle after this test. Not knowing Columbia was still full of nitrogen, they immediately lost consciousness.

Another worker saw what had happened, and rushed to put on an air pack to help them, dragging them from the compartment. Only three of the five men could be revived.

Complicating matters, an ambulance sent to help was held and searched for seven minute by security guards, who did not know there was a problem. Ultimately, one worker died at the scene, and another on the way to the hospital.

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# The last Space Shuttle commander

Christopher J Ferguson reveals his regret at the retirement of NASA's iconic Space Shuttle in 2011, but tells us how he's now looking forward to working on the next generation of spacecraft at Boeing

**Interviewed by Jonathan O'Callaghan**

**BIOGRAPHY**

**Christopher J Ferguson**

Born on 1 September 1961, Ferguson is a retired US Navy Captain and NASA astronaut. He was the pilot on STS-115 in September 2006 and commander for STS-126 in November 2008, before serving as the final Space Shuttle commander aboard Atlantis for the STS-135 mission in July 2011. He now works at Boeing, helping the company build a new generation of space vehicle with its CST-100 capsule under contract from NASA.

**Why did you decide to become an astronaut?**
I've always had this fascination with things I didn't completely understand. I spent a lot of time in the Navy only because I could never really understand how an aircraft carrier worked - I thought it was just one of the most intriguing places on Earth. So I was in the Navy for a good 15 years and then the next logical step, the next thing I really couldn't understand, was what it's like to operate in space. As I matured in my Navy career I realised I had been through most of the steps the early astronauts had done, and I thought I'd give it a go. I started applying as early as 1991 and I endured a couple of rejections, but as with most good things in life persistence certainly pays off and I finally got picked to join NASA in 1998.

**Was it an exciting time to be involved in NASA's space programme?**
What a ride it was. It was kind of the heyday of the Space Shuttle programme. The ISS [International Space Station] was just coming online and we knew that we had an incredible amount of Space Shuttle flights, 35 in total, dedicated to the space station's construction. I don't think the public could truly appreciate the magnitude of the effort, but when you think there were 35 Space Shuttle missions, each of them carrying about 50,000 pounds [22,500 kilograms] of cargo into space, and not to mention the many Soyuz flights, Progress cargo flights and Proton flights with the Russian segments, it was truly a global construction effort and I look back at my time and think I was just so lucky to be a part of the whole thing.

**How did it feel to be selected for your first flight as the pilot on STS-115 in September 2006?**
There are few things in life that are comparable to getting selected to go on a spaceflight. I was just thrilled. Of course our training for that flight was delayed for over two and a half years because of what happened with Columbia [in February 2003], but like anything good it's worth waiting for in life. I flew in pretty quick succession, 2006, 2008 and then in 2011, so I was very, very fortunate. It's one of those moments in life you'll never forget, getting picked and realising 'boy, you know, you're really going to do this'. So it was a great joy.

**What was it like on your first flight?**
I really didn't know what to expect. You hang around the office long enough and you begin to hear everybody's stories about what their experiences were like, but while you can simulate most things [on the ground] you can never simulate what it's like to be in zero-g. I remember a moment probably two or three minutes after launch when I looked out the window off to my right and saw the east coast of the United States just kind of disappear beneath us. And I looked outside, then inside, and outside again and I thought, you know, this is amazing. We are flying into space. From that moment I was very aware how magnificent this was. Here I am in a spaceship that looks an awful lot like an aeroplane and we are literally flying this thing into space.

**Having been a test pilot, how did it feel to pilot the Space Shuttle?**
You're so prepared, especially for what we call the dynamic phases of flight, ascent and re-entry, but between all that it's completely different. It's a different world. You fly backwards, you fly upside down, and after a while you forget you're even in an aeroplane because it doesn't behave like one in orbit. You usually are upside down and backwards going tail first looking at the Earth, and what a

"There are few things in life that are comparable to getting selected to go on a spaceflight"

# The last Space Shuttle commander

FERGUSON HURLEY MAGNUS WALHEIM
STS 135
CHRIS FERGUSON
NASA

**Christopher Ferguson was the commander on STS-135, the last flight of NASA's iconic Space Shuttle that was in operation from April 1981 to July 2011**

Ferguson on the ISS, where Space Shuttle Atlantis spent over eight days docked in July 2011

surreal experience that is. I can recall a moment we actually flew over a couple of hurricanes that were in the Atlantic Ocean and to be able to look out the overhead windows straight into the eye of a hurricane is one of those 'pinch me' moments in space, when you can't believe you're actually doing what you're doing.

"To build a spacecraft is not just a once-in-a-lifetime opportunity, it's a once-in-a-multi-generation opportunity"

**What was it like to be chosen as the commander for the final Space Shuttle flight, STS-135?**
It was sort of a mixed blessing for me. I knew that my name was up in the rotation [for the last mission] but it was a flight that might not happen, it was kind of like being a part of Apollo 18 [laughs]. Then the Space Act of 2010 kind of baselined the Congressional funding for this additional flight [so it went ahead]. But what I realised not too far into training was that I was not just a crewmember on a Space Shuttle flight, but it was sort of my job to say goodbye to everybody, folks that had worked an entire career on this vehicle. They knew they were going to head into retirement at best and perhaps at worst they were going to lose their job in the middle of their career. So it became a very delicate balancing act to kind of sing the praises of the Shuttle programme as a whole, and at the same time respect and acknowledge the people who were soon going to lose their jobs who had been a part of it for so many decades.

**Do you think it was the right decision to retire the Space Shuttle?**
If you had asked me back in 2003, which is when the decision was made to retire the Space Shuttle, I would have said of course this is right after losing Columbia. Losing two out of the five Space Shuttles is not great odds, and if we continued to fly this thing for another 20 years, chances were we were going to lose another one. So at the time I would have said, knowing that something else [the Constellation programme] was on the horizon, it's probably not a bad idea for us to move on. But as the days got closer and then the Obama administration cancelled the Constellation programme [in 2010] we realised there was going to be a substantial gap between the Space Shuttle and whatever followed it. At those moments I gave pause and regretted feeling the way I did back in 2003 – that it was a good idea to shut the Space Shuttle programme down. I think looking at all the events that had transpired between 2003 and 2010 the wise thing would have been to preserve America's access to low-Earth orbit [LEO] and to continue flying the Space Shuttle until we had clear direction and an approved plan by Congress to get back to LEO at a defined date. We're in that gap now, which is what I'm a part of with Boeing, but after realising the impact of it I would have said we should keep flying it perhaps just twice a year to know that we can get [to LEO] and we're not reliant exclusively on the Russians.

**Were you proud to be chosen as the last commander of the Space Shuttle?**
Yeah, absolutely, but again it was sort of bittersweet putting the Shuttle programme to bed. In four years when we [Boeing] are ready to fly I'm going to look back and think we've spent a long time to get back to something that we used to do at will for three decades in the Shuttle programme.

**What was the most notable moment from that final flight?**
One in particular was the night before re-entry. The last flight control team had come into the flight control centre and I had the opportunity to expound a little bit on my thoughts with them, and tell them all to just enjoy the moment and to thank them profusely on behalf of all the astronauts for what they have done throughout the years. Those one-on-one discussions with the flight control teams as they left was probably the most noteworthy memory from that last flight.

**Following the retirement of the Shuttle, why did you decide to join Boeing?**
I'd been talking to Boeing a little bit on and off before the flight, and then afterwards I knew that

Boeing was one of the potential providers for what we call [NASA's] Commercial Crew service along with SpaceX and Sierra Nevada Corporation. And I knew Sierra Nevada had their astronaut, SpaceX had theirs, but Boeing didn't have one. When I say 'their astronaut', it's just nice to have somebody on board helping guide the development of the interior of the spacecraft from a crew's perspective and to make sure it satisfies the intent of the mission. We have a lot of experience, 50 years of flying in space, and the astronauts really are the ones who know how well a craft operates in space. I knew I didn't want to spend six months on the space station [as an ISS astronaut] as the training templates for the ISS missions are very rigorous and long and I kind of thought it was time for me to turn that over to some of the younger astronauts, so here was an opportunity to join a company who was potentially working on the next craft [the CST-100 capsule] that will launch from American soil and take astronauts up, and I thought how can I possibly turn something like this down. And I haven't looked back, it's been a joy ever since I got to Boeing about a year and a half ago.

**Is it exciting to be working on the next generation of space vehicles with Boeing's CST-100 capsule?**
Yeah, and I tell everybody working with me and for me that to build a spacecraft is not just a once-in-a-lifetime opportunity, it's a once-in-a-multi-generation opportunity. I mean the last time we did this was in the mid-Seventies as we were designing the Space Shuttle, and a lot of the people associated with that work have retired or are no longer with us, and that was a long time ago. So a lot of this we're having to re-learn, but I'm amazed at the depth and breadth that Boeing has and their ability to resurrect this latent talent that it had within, because you know Boeing's been involved in just about every human spacecraft since the Mercury days. I look at this team I'm working with and I'm humbled in their presence because I thought I knew it all, but in reality I knew very little. I'm very proud in our effort and I look forward to seeing us back in orbit again very soon.

**Would you like to fly on the CST-100?**
You know I would love to, but I get back to my original comment of this being a business for the younger astronauts. But if Boeing asks me to do it I'll have to have a very long conversation with my lovely wife and ask her if she's ready to actually go through with something like this again. It's hard to let go, the question is will I be able to or not. That day is still a way off, we're not scheduled to fly a human spaceflight until the end of 2018, so there's a lot of open ocean between now and that date. But if they ask me I'll seriously consider it, let's leave it that way.

**What are you guys working on at the moment?**
Well now we're working on finding our landing sites. We're planning on the craft coming down on land, so we'll come down under parachutes to a landing site. Finding that perfect landing site in the US, even though the US is a big country, is difficult because there are just so many constraints that drive you to just a few select areas. We want a large enough area about eight kilometres (five miles) in diameter to provide for wind variations and de-orbit entry variations, so we want to give ourselves a real big target, and finding a big target like that even in the desolate areas of the western US is not exactly easy to do. So we're looking for up to four different landing sites to give us many opportunities to return. We are also actively developing our mock-up. The interior geometry of the spacecraft has largely been defined and the exterior geometry has been defined, so we're just now in the stages of making a mock-up to make sure that it works and that the crew has enough room to manoeuvre and function within this very limited environment, which is much smaller than the Space Shuttle. And also the aerodynamics team are working very hard on ascent aerodynamics, and that's done in collaboration with the United Launch Alliance [ULA], who's the provider of the Atlas V launch vehicle [that the CST-100 will use].

**Is Boeing co-operating with its competitors, Sierra Nevada Corporation and SpaceX?**
No, I would have to say it's an all-out competition. I do maintain some back channel communication with my fellow former [NASA] colleagues at those two companies, but just to the extent that we make sure we understand NASA's requirements. As far as the design is concerned everything is considered proprietary. We want to make sure we keep our design and the way we intend to do business as under wraps as possible. We [Boeing] have got a lot of experience doing this and we like that advantage. We think that we have a solid lead in terms of human space travel.

**Is the privatisation of spaceflight important for the future of space travel?**
I think about it in terms of what the possibilities are. I sort of envision a Boeing, or Sierra Nevada or SpaceX, astronaut heading to their vehicle outfitted in Boeing regalia. Now you've got really the first vestiges of a commercial space line where anybody with a lot of money, at least in the early stages of the programme, could do something like this. Air travel was the same way initially back in the Twenties when it started to take-off – only the wealthy did it. Rocket travel to LEO will be just the same way initially, but the more you do it the more confidence that the public has in your ability to do it safely and the more customers you fly you begin to get into economies of scale and suddenly it's within the grasp of people who would never have been able to consider something like this even ten years ago. So from that perspective I think it's very exciting. A commercial pilot taking a commercial paying crew into space is just kind of mind-boggling if you think about it, but I can see in ten years it being a distinct reality.

Commander Chris Ferguson and pilot Doug Hurley on the Space Shuttle's flight deck during STS-135

Ferguson now works for Boeing, which is planning a manned launch of its new CST-100 capsule in late 2019

The final voyage of Space Shuttle Atlantis in July 2011 marked the end of the Shuttle era

© NASA; BLM Nevada/Boeing

# A year in space

## Within days of spending a record year in space in 2015, NASA astronaut Scott Kelly discussed his experience and how it felt to be back on Earth

**Interviewed by David Crookes**

**Did anything surprise you about your year in space or was it what you expected?**
I think the only big surprise was how long a year is. It seemed like I'd lived there forever. It seemed longer than I thought it would be. But having flown before, I paced myself appropriately and felt good about that.

**What struck you the most looking down at Earth each day?**
The Earth is a beautiful planet and practically everything to us. It's very important to our survival and the [International] Space Station is a great vantage point to observe it and to share our planet in pictures. You also notice how the atmosphere looks and how fragile it looks. It makes you more of an environmentalist looking down at it.

**How do you stay a year without going bananas?**
Occasionally you do go bananas. I think NASA does a good job at selecting people who are able to deal with those kinds of environments and who can stay hyper-focused on what they need to do. It's critical to your survival. The Navy had a term of "compartmentalise", to focus on the task at hand and take it one day at a time, which is very important. I tried to have milestones that were close: when is the next crew arriving, when is the next visiting vehicle arriving, the next EVA, the next robotics, the next science activity. That made a big difference to me.

**Mark [your twin brother] said you did notice some physical changes upon your return. Can you detail those?**
Some of you may know that I flew 159 days last time and when I came back I was feeling pretty good. There is always a certain amount of soreness and fatigue but, initially, this time coming out of the capsule, I felt better than I did last time. But those two lines have crossed and my level of muscle soreness and fatigue is a lot higher than it was last time. It almost makes me think there is a linear function to it. I also have an issue with my skin because it didn't touch anything for so long so any significant contact is very sensitive. It's almost a burning feeling when I sit or lie or walk.

"I will never be done with space. I will always be involved, though I doubt I would fly again with NASA"

S. KELLY
КЕЛЛИ

Commander Kelly gives the thumbs up just minutes after leaving the Soyuz TMA-18M spacecraft

**You've said Mars is 'clearly doable' – physically or psychologically? What about the science?**
I think there are still things we have to learn but I think we can learn them. There are challenges we still have, like the radiation issue: if you take six months to get there, the crew is getting a lot of radiation. If you get there quicker, then that's less radiation. Having a robust life-support system is important as is being able to maintain it and, you know, there are the medical aspects. But I think we know enough, and I think we're close enough that if we made the choice, 'hey we're going to do this, we're going to set a goal, we're going to set a time,' then yes, I think we can do it.

**If you got out of a capsule at Mars, there wouldn't be people to help you out. Do you feel you could have got out of a capsule or spacecraft, put on a spacesuit and set up camp on Mars?**
I actually learned something on this flight that I didn't really fully appreciate and that is when Soyuz [spacecraft] lands upright, you're pretty much getting out of it yourself. I always had the assumption that someone would reach down and unstrap the commander and sort of somehow pull him out, but when it lands upright he basically got half way out and unstrapped himself, which is not easy in that thing, and they pulled him out.

I had to unstrap, close the hatch, move over to his seat, open the hatch, get up outside and get myself about half way out before they could pull me out, so I got a sense for, yes, I could do that. Mars has less gravity, which is helpful as well. But I think if we'd had a ballistic landing and landed upright, I could have gotten out of the capsule. You'd probably sit there for a long time to adapt and then try to do whatever you needed to continue with your business.

**You mentioned a week or so [before you landed] about the size of your crew quarters not being large enough. Can you elaborate a little bit?**
I didn't say they weren't large enough. I think what I said is that I spent a lot of time in that very small space. If you can consider the fact that you sleep in there and then you're going in there at lunch time to

KELLY
YEAR IN SPACE
КОРНИЕНКО
ГОД В КОСМОСЕ
ISS 43 · 44 · 45 · 46 МКС

**BIOGRAPHY**

**Scott Kelly**

On 27 March 2015, Scott Kelly became the first American astronaut to embark on a mission that would see him spend 340 days on board the International Space Station. Accompanied by cosmonaut Mikhail Korniyenko, the mission was to better understand how the human body is able to adapt to such a long period away from Earth. As a bonus, Kelly could be compared to his twin brother, former astronaut Mark Kelly. It was the highlight of a NASA career that had seen him embark on three previous flights, plus a spell aboard the Aquarius underwater laboratory. In total, he has spent 520 days in space.

work, email or whatever, and then you spend a few hours in the evening, I probably spent six months in that little box. But that doesn't mean it is too small. I think, as far as size is concerned, it's appropriate.

The point I was trying to make is that if you're going to Mars, when you're in a smaller vehicle than the ISS and you're living on top of one another, having that space that you spend so much time in is very important and you need to make it as perfect as you can with regards to the air, temperature, having interfaces with the systems, communications, entertainment and noise abatement. You're going be sleeping, living, exercising and eating and doing everything right on top of one another.

**Was there a particular moment when you felt especially homesick?**

There are certainly family issues that happen – crises like my last flight. As you all know, my sister-in-law Gabby [former Democratic Congresswoman Gabrielle Giffords, wife of Scott's twin Mark] was shot and I wouldn't characterise it as feeling homesick but certainly, you know, you feel like you want to be there. But it's not like I felt physically affected or that it affected my ability to do my job. You certainly long for things at home but I wouldn't characterise it as having the blues or something like that.

**In regards to the twin study, is there an area of that research that you're most interested in?**

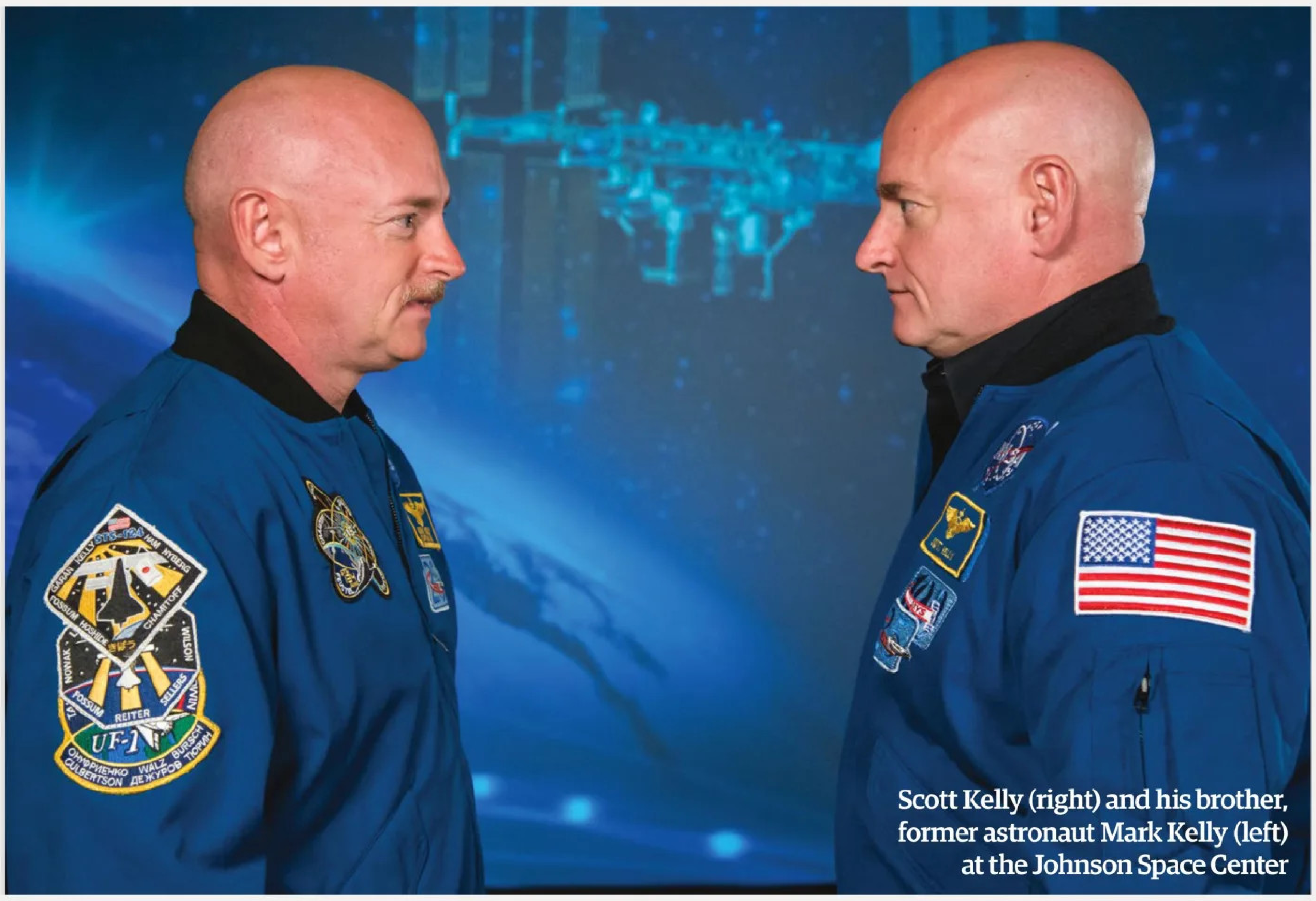
Absolutely, I think the genetic base part of it: my DNA being almost identical and what the effects of spaceflight are on that. This is NASA's first time getting involved in those kinds of studies in space. This kind of genetic-based research is something that's new for us so that, to me, is very exciting and obviously personal. There is information that we will be able to find out about ourselves and our families and my kids. There are some questions about how that's dealt with from a privacy issue but it's something that we can talk about in the future.

**In the brief time you have had with your brother, have you noticed anything different?**

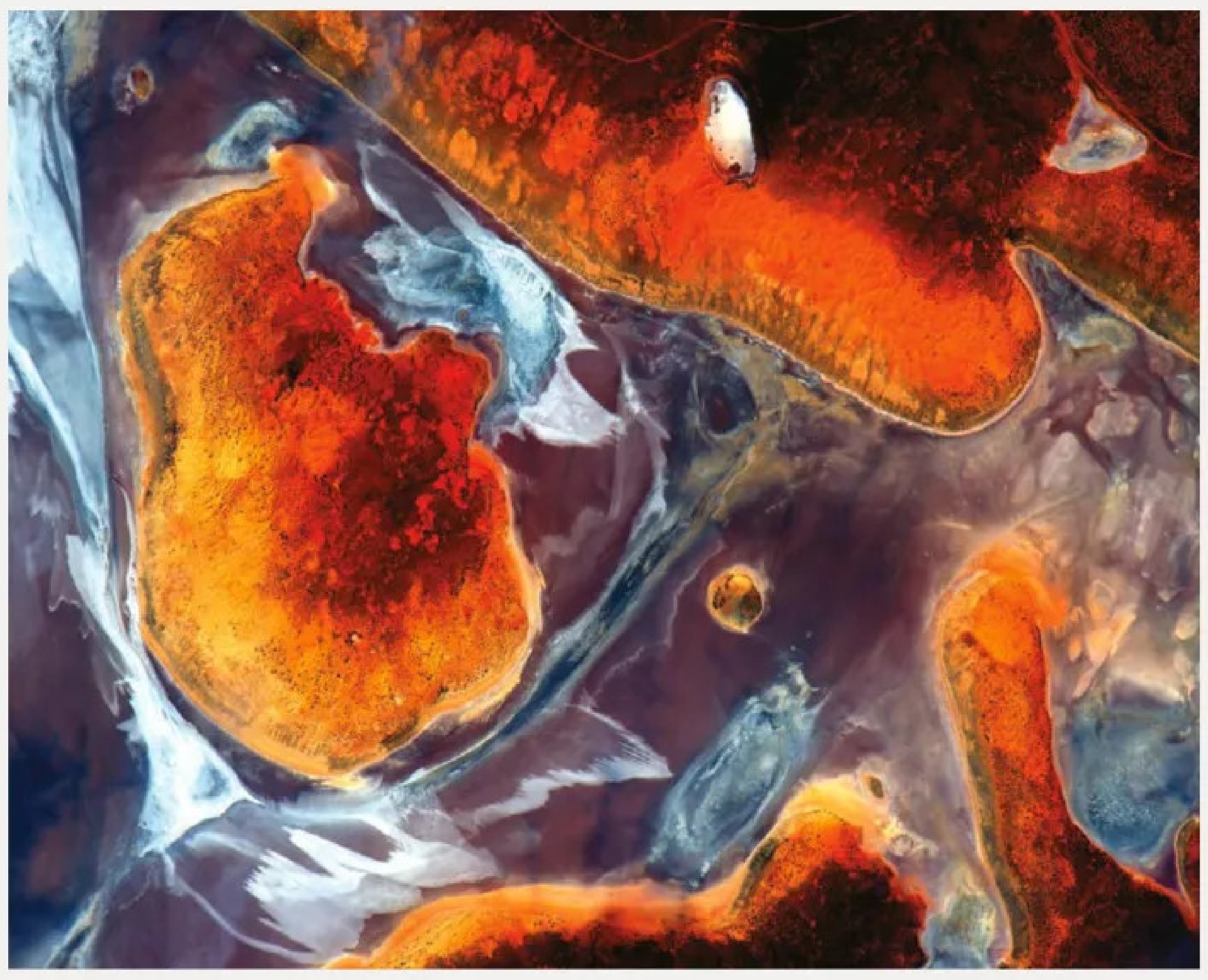
He's got a better tan. I don't think he goes to the tanning bed though. I think it's because he plays too much golf. He has too much time on his hands. [smiles] Nothing that comes to mind right now. We're the same height by the way. Gravity pushes you back down to size.

**Was it more difficult mentally or physically adjusting to space?**

Adjusting to space is easier than adjusting to Earth



Scott Kelly (right) and his brother, former astronaut Mark Kelly (left) at the Johnson Space Center



Kelly shared a series of photographs taken from the ISS during a flyover of Australia under the hashtag #EarthArt

The first flower grown in space onboard the ISS. Kelly claims looking down at Earth emphasises its fragility

Kelly claims it is harder to come back to gravity than it is to leave gravity

for me. I don't think I ever felt completely normal up there – there's always some little subtlety of how you're feeling, even after you been up there for 340 days – but, yes, I think coming back to gravity is much harder than leaving gravity. So, I don't know, maybe the aliens have got it a lot easier than we do.

**What did you do in your spare time when you were in space for the year?**
Talk on the phone, email, take pictures, read, watch TV shows and movies, that's most of it.

**How busy have you been since returning?**
So we landed at 1am. We landed in Kazakhstan and I flew to Norway and did some medical tests. From Norway we were going to fly to [the Canadian Forces Base in] Goose Bay, Canada but the weather was bad and we landed in Gander. A lot of the time on the plane I was trying to sleep, which was kind of hard because I was uncomfortable and sore. But I did sleep. Then, when we got back I went to the JSC (Johnson Space Center) to some of the medical facilities and did some tests, had blood drawn and did this functional fitness test, which is kind of a test of your physical ability to do things. I got home at about 4am, jumped in my pool and was up by about 9am, back at work at 10am for more medical tests and did this functional fitness test again. I did some other tests on my muscle strength that took some time. I've had two hours of MRI scans and a Japanese experiment so it's been pretty busy.

**Why were you so eager to jump in to your pool?**
Even though I took a shower in Canada, I hadn't had running water for 340 days and it's something you really miss. We make do with not having a shower onboard and you don't feel dirty, but you definitely feel like you would like to jump in a pool. So I did.

**You're being offered up as the poster boy for Mars. How do you feel about that?**
I don't know about 'the poster boy' but I think NASA does a good job of picking people for these types of things and if it wasn't me doing this, it would have been one of my colleagues and they would have, I'm sure, done just as good a job as I did, or better. It just so happens that I was the first person to do this and it doesn't necessarily mean I'm the best. We have a lot of talented and dedicated people in our office.

**Are you having a little trouble with things not behaving in the way they do in microgravity?**
The first thing I tried to throw on a table I missed. I tried to shoot some basketballs and I didn't get any of them in the net, not that I'm a good basketball player anyway. What's really hard [in space] is throwing something straight. You end up wafting everything.

**Can you tell us of your experience of Extra-Vehicular Activities (EVAs)?**
Those spacewalks are very technically challenging and can be physically challenging depending on what you're doing in the time you're outside. Ours varied from over several hours to over five hours, so very different. But I guess one main feeling I had after doing those first two is a sense that you have all these people involved in this and they all do great

Kelly believes that virtual reality has a lot of potential for space, particularly in assisting with EVAs and spacewalks

© NASA

"I think coming back to gravity is much harder than leaving gravity. Maybe the aliens have got it a lot easier than we do"

work, and they're very, very important to the process. But in the end, you can only rely on your EVA buddy and you're very reliant on one another for your lives, literally. That's kind of the main takeaway I had from those experiences. The view is great, too. It's pretty amazing.

**You tested Microsoft's HoloLens device - do you think virtual reality has potential in space?**
I think virtual reality has a lot of potential. [The device has] cameras on it and we could see a display in the field of view where the person on the ground could be drawing and pointing to things. I could be doing the same thing during a maintenance procedure. I could say, "Is this the connector you're talking about?" And the person could just write an error in your field of view. We messed around with it for two hours and immediately I sensed this is a capability we could use right now.

**Could you talk about any vision changes you experienced during the mission compared to previous ones and whether you've noticed any differences since you returned?**
It was very consistent with my last flight from a subjective point of view. We were collecting more data this time onboard, so we'll have a better insight [about] when those changes occurred and how they were in flight versus the ground. But I don't think that, at least subjectively, it was much different than my last experience in which I noticed some changes [in the beginning] that then kind of levelled off.

**Did the extra six months make a difference?**
[With a six month stay] you can kind of see the end and you think, "Okay, I launched in October and I'm coming back in March, I can envision getting there." But when you launch in March and you're thinking about coming back the next March, it is not something that you can really comprehend. I think the perfect duration for a spaceflight is somewhere on the order of two-and-a-half to three months. When you get to [that stage] you think, "I've really been here for a long time." To know that you have nine months to go is kind of hard to get your head around. As far as coming back, I was kind of surprised [at] how I do feel different physically than the last time with regard to muscle soreness and joint pain, and then there is the skin issue.

**Are you done with space now or are you hoping to go back up?**
I will never be done with space. I will always be involved. You know, even my brother's been retired for a bunch of years and he still hasn't given up the idea that he's going to fly in space again. I doubt I would fly again with NASA, having spent more time in space than any American. We have so many talented people in our office so there's no reason for me to fly me again. But there's a lot of exciting possibilities out there, maybe in the commercial aspect. They might need a guy like me someday.

**Should "normal" people be able to go to space?**
I think everyone should be able to go to space. It's going to depend on the person and what kind of experience they would want, so it'd be great to have a variety of ways to get to space or near space, maybe for the view. You get a pretty spectacular view without going all the way to the edge of space.

**Could you talk about how you managed the workflow - did you have to sometimes push back against the ground team on how much they wanted to do?**
I've always had a great working relationship with the ground team and been very open with them. It's a team effort. There are priorities and there are higher priorities, and you try to get the higher stuff done. The spaceflight surgeons help to manage our fatigue level and we were all kind of a big team doing that. In my experience it's always worked well.

**You will go down in American space history with two NASA records. How does it feel to be the guy to set these records?**
These records are made to be broken and there's this guy that's going to launch here in the next couple of weeks who's going to break my number of days record, which is great. I'm a big believer in pushing the envelope on this kind of stuff. I don't know when someone will have more than 340 days in space next, but hopefully it won't be too long.

**You have rekindled interest in space - what do you take away from that?**
I think space is important; I think it's our future. It helps our economy grow and it provides technology. I think there are things we are going to discover about our experience in space in the International Space Station that we don't even know now. It's kind of like when the astronauts were walking on the Moon they were trying to develop more advanced computers and technology. I think it's great.

# Beyond the Moon

NASA's unmanned probes have traversed vast distances – some have even exited the Sun's heliosphere and begun their journey into interstellar space. Here are some of the most intriguing missions and their destinations...

**Helios**

**Helios A, 10 December 1974; Helios B, 15 January 1976**

A joint venture between NASA and DFVLR, the space agency of the then-West Germany, the Helios probes squeezed even closer to the Sun than the orbit of Mercury and collected data that improved our understanding of cosmic rays and the solar wind.

**Magellan**

**4 May 1989**

The first interplanetary mission to be launched from a Space Shuttle, its job was to radar-map Venus – a purely optical survey was impossible due to the planet's thick, toxic atmosphere.

**Mariner programme**

**1962-1973**

The Mariner programme included some of the most famous unmanned probes to orbit our planetary neighbours. The ten-mission program investigated Mercury, Venus and Mars.

## The Hubble Space Telescope

### 24 April 1990

Watching the skies from Low Earth Orbit since 1993, when a manned mission installed corrective optics to compensate for a flaw in its primary mirror, this space telescope has done a great deal over its long mission to increase our understanding of the universe.

## Galileo

### 18 October 1989

Galileo's six-year journey saw it become the first manmade object to orbit Jupiter, where it sent back data on the gas giant and its many moons from its orbiter and atmospheric-entry probe.

## Cassini-Huygens

### 15 October 1997

NASA set its sights even further with this probe, which headed to iconic, evocative Saturn. The Huygens part of the probe landed on the moon Titan, the first landing of a probe in the outer Solar System, while the Cassini element was eventually deliberately crashed into Saturn.

## Viking

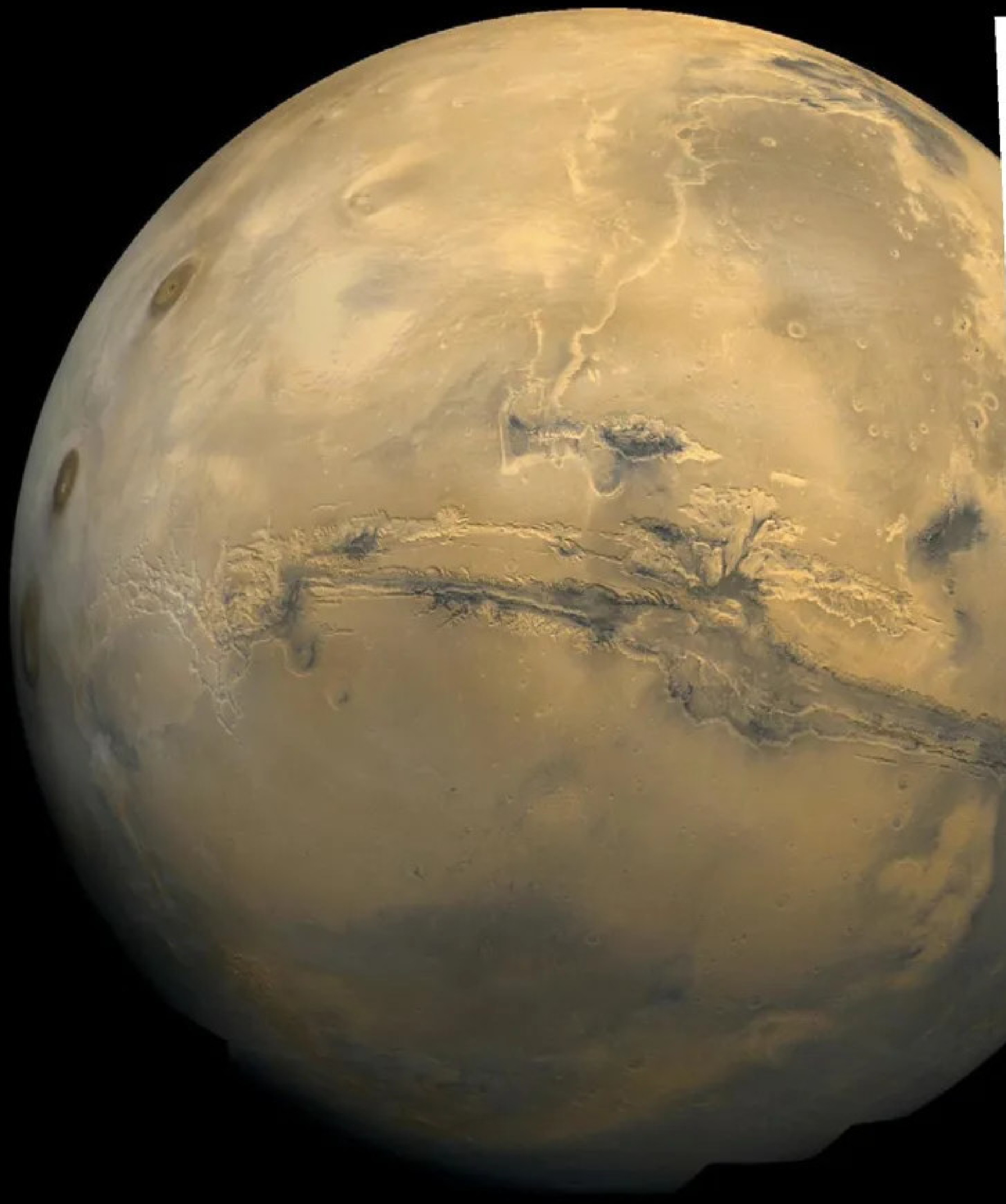
### Viking 1, 20 August 1975; Viking 2, 9 September 1975

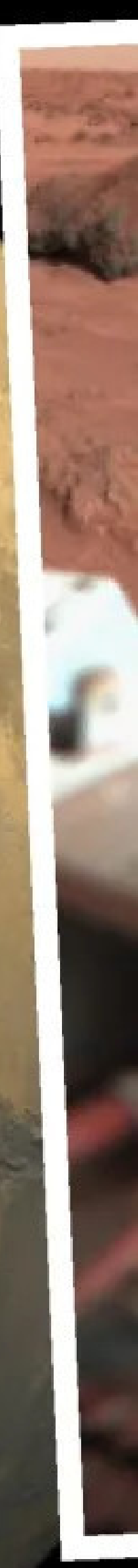
This pair of two-part probes was made up of an orbiter and lander apiece; to study Mars from space and to perform experiments on the Martian surface itself. NASA has since landed other craft, notably the Mars rovers, on the Red Planet.

## To infinity and beyond

### 1972 – ongoing

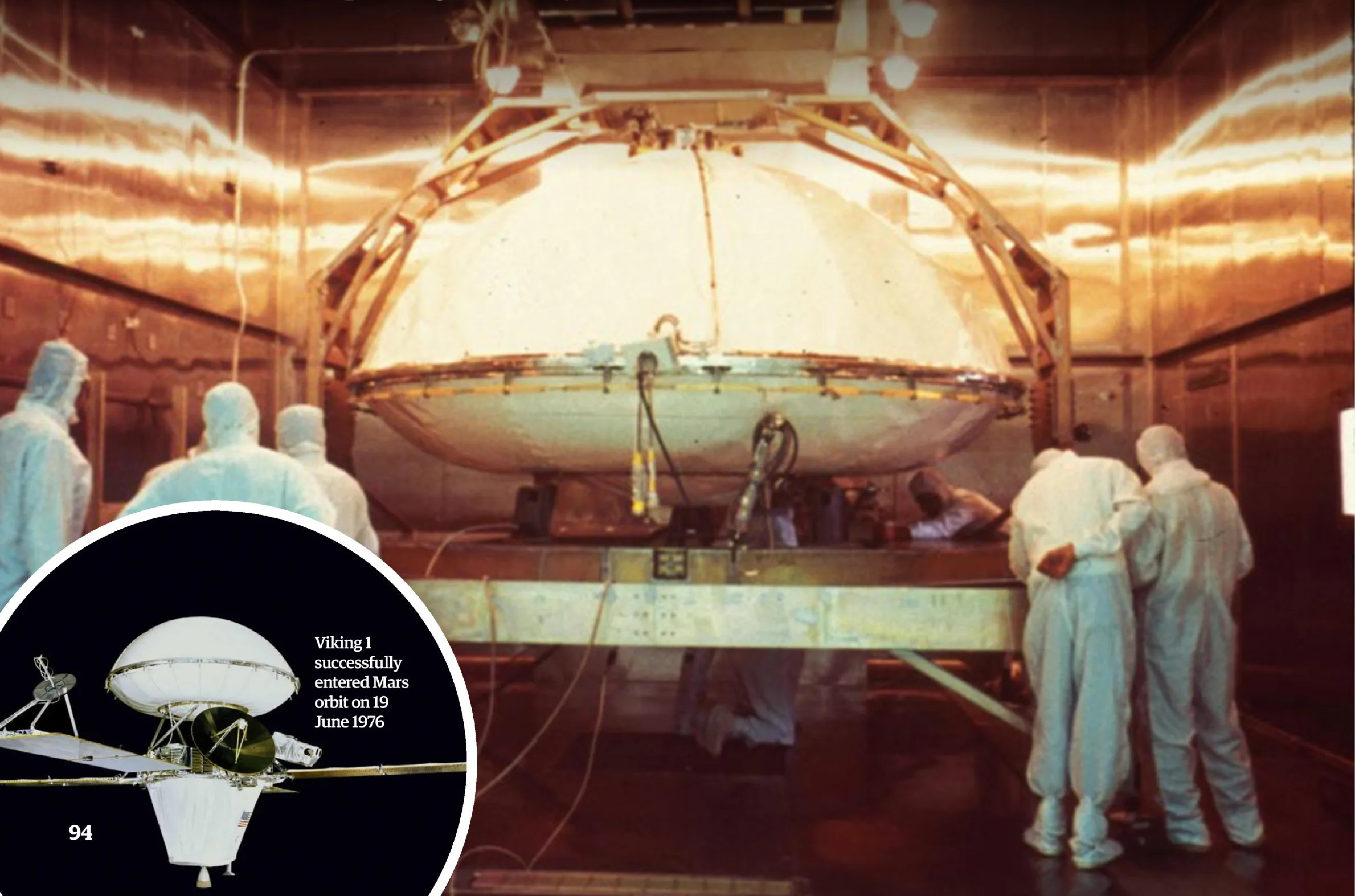
Several probes have now made their way into interstellar space – Pioneers 10 and 11, Voyagers 1 and 2, and New Horizons, although this last is the only mission to have deliberately aimed for this goal before launch. NASA remains the only space agency to have sent probes beyond the boundaries of the Solar System.



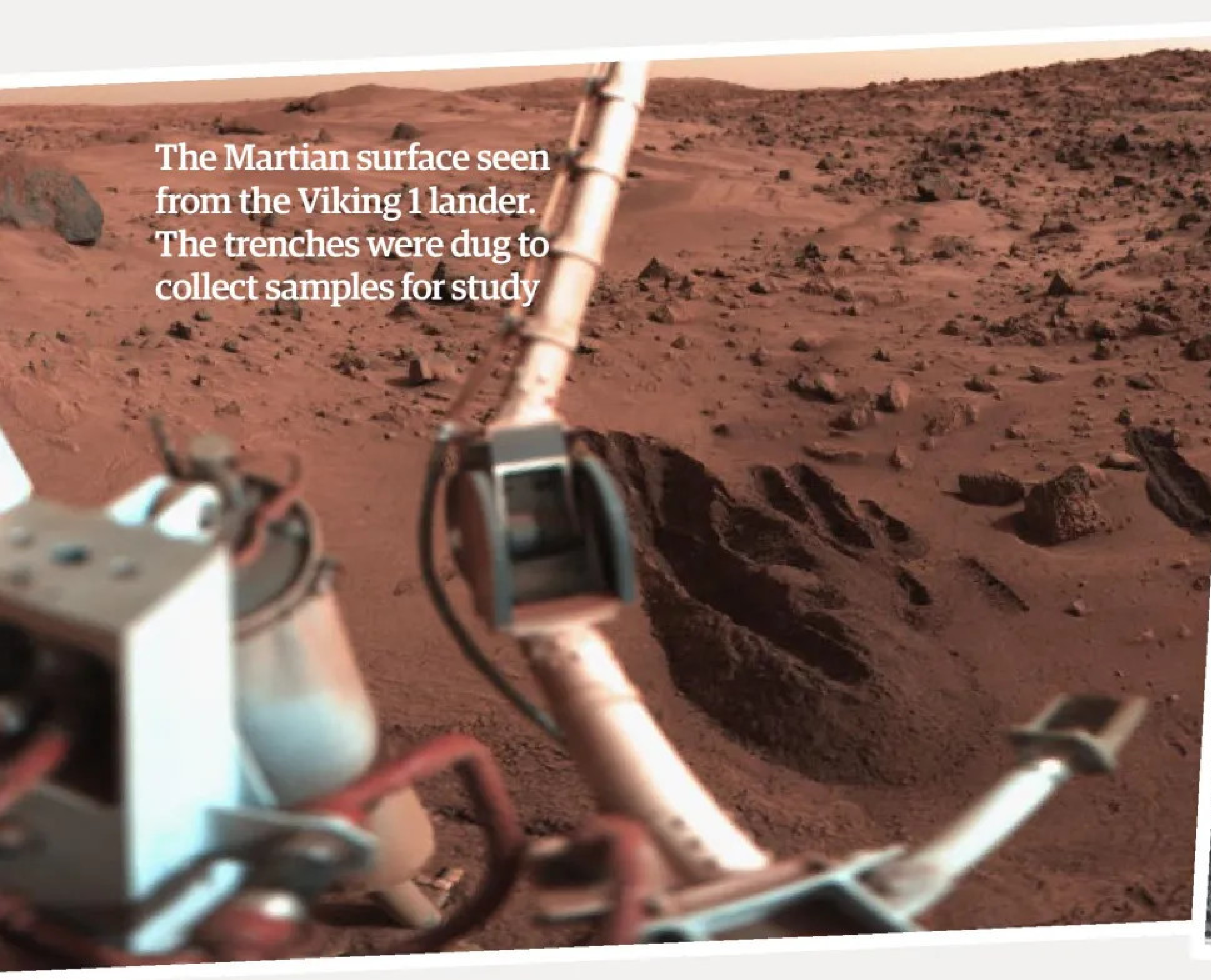


# Mission to Mars: the Viking probes

In the mid-1970s, twin NASA spacecraft transformed our understanding of the Red Planet, Mars, paving the way for later missions



Viking 1 successfully entered Mars orbit on 19 June 1976

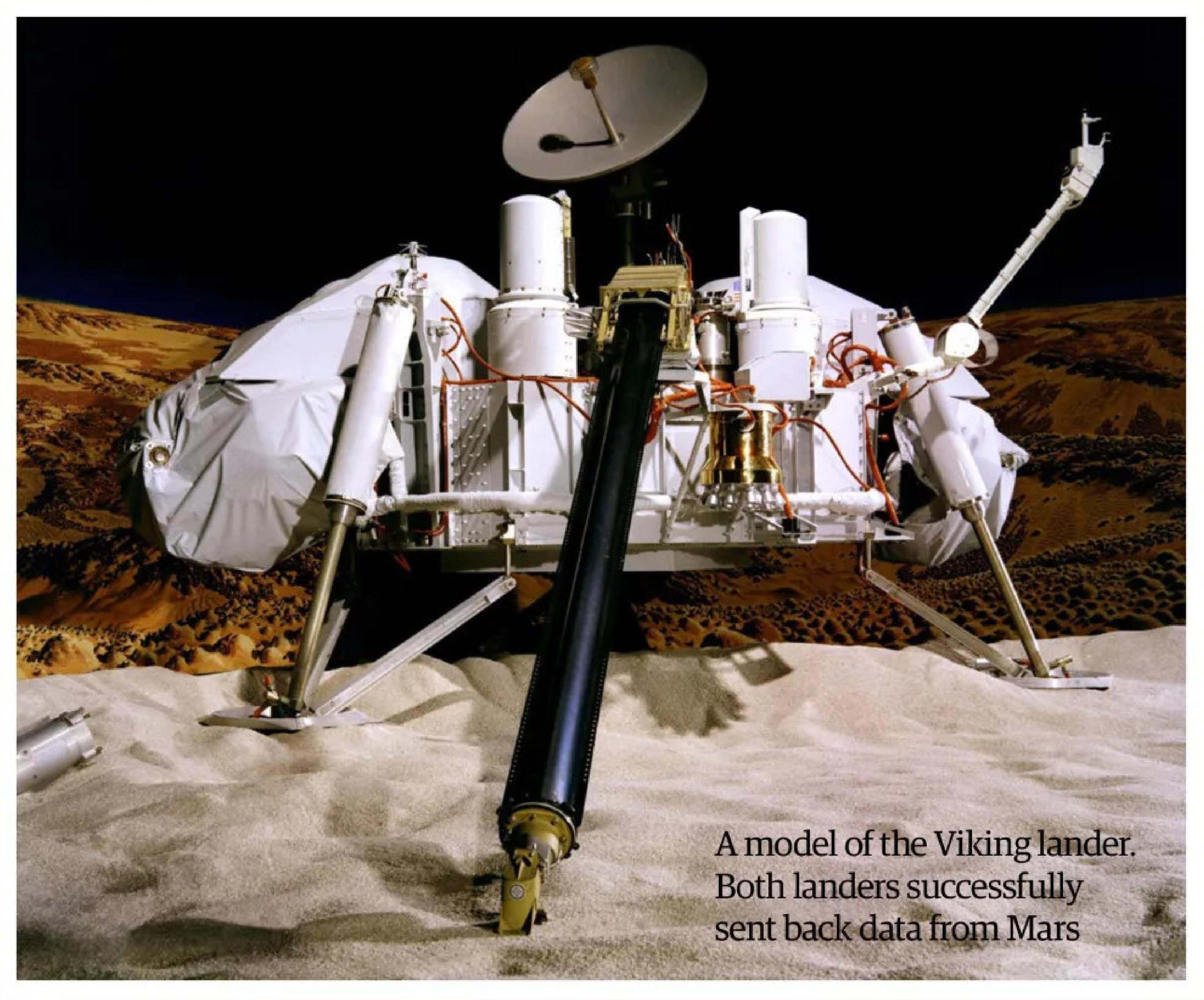


The Martian surface seen from the Viking 1 lander. The trenches were dug to collect samples for study

In the early days of the Space Age, Mars was an obvious target for robot spaceprobes. Despite being a little further away than cloud-wrapped Venus, its thin, transparent atmosphere would allow spacecraft to send back images as they flew past. So Mars became a new lap of the Space Race between the US and the Soviet Union – and one where NASA soon took the lead. As the Soviets endured a string of failures throughout the 1960s, the US agency had better luck with its Mariner 4, 6 and 7 spacecraft, each of which flew past the planet and sent back a few precious pictures of its surface.

The obvious next step was for a probe to orbit and map Mars, and Mariner 9's arrival in 1971 made it the first mission ever to orbit another planet. The spacecraft arrived during a global dust storm that blocked the surface from view, but a few weeks later, as the dust settled back onto the landscape, a new Mars began to appear. All three of NASA's earlier probes had coincidentally passed over the planet's cratered southern highlands, but now Mariner 9's view of the planet's northern hemisphere revealed dried-out lakebeds and river channels, giant volcanoes and deep canyons.

The discoveries made by Mariner 9 paved the way for NASA's next Mars mission – the Viking programme. These launches would each send a pair of spacecraft to Mars – an orbiter to study the planet from space, and a lander that would touch down on the surface before sending back information about the Martian environment and analysing the soil.



A model of the Viking lander. Both landers successfully sent back data from Mars

Launched on 20 August 1975, Viking 1 arrived in Martian orbit on 19 June 1976. Engineers and scientists at NASA's Jet Propulsion Laboratory initially planned a landing for 4 July in celebration of the bicentennial of the US Declaration of Independence (although technically, NASA had been beaten to the surface by the Soviet Mars 3 mission, which made a successful descent four years earlier only to fail 20 seconds after landing).

These plans were thrown into chaos when the orbiter returned its first detailed pictures of the proposed landing area, a region called Chryse Planitia. The images were much clearer than Mariner's (partly because of camera improvements, but also because obscuring dust had lingered in the Martian atmosphere throughout Mariner 9's mission), and they clearly showed the potential landing zones were not the smooth plains that had been expected.

So the JPL team were forced back to the drawing board, and after a new spot in Chryse was found, Viking 1 finally landed on 20 July. Viking 2, launched on 9 September 1975, arrived in orbit on 7 August 1976, and its lander touched down on 3 September, after similar debates, in the Utopia Planitia region.

Getting the 572-kg (1,258-lb) lander onto the Martian surface was an impressive feat of engineering – landing was a complex procedure that began by separating from the orbiter 'mother ship' and firing rockets to slow the lander's speed and drop it out of orbit. A protective aeroshell then protected the probes in the upper reaches of the thin atmosphere, before parachutes deployed about 6 km (3.7 miles) above the ground. Finally, the parachutes were released and retro-rockets fired to lower the lander gently onto the ground.

While Viking Orbiters 1 and 2 continued to survey Mars from space until 1980 and 1978 respectively, attention now focused on the landing sites. Each lander was equipped with cameras, a weather station for monitoring wind speeds, temperature and other conditions, a steerable boom arm for sampling dust from the surface, and an onboard geology lab. A gas chromatograph device vapourised soil samples and identified their individual chemical components, while other experiments studied the magnetic and crystalline properties of the soil.

Although the two landing sites shared some obvious characteristics such as abundant red dust and a salmon-pink sky, in other ways they proved quite different. Lander 1's location in Chryse was set in a rolling landscape strewn with small rocks, while Lander 2's Utopia site was flatter, but far more treacherous thanks to a scattering of breezeblock-sized boulders. Orbital photographs and data from the landers have since led scientists to conclude that Chryse is an ancient flood plain whose scattered rocks were deposited by ancient water flows. The boulders on Utopia Planitia, in contrast, appear volcanic in origin, and were probably scattered across the desert landscape as debris from a powerful ancient eruption.

The Viking weather stations, meanwhile, provided information about conditions on the surface. Lander 1 soon confirmed that Martian air pressure is a mere 1 per cent of Earth's, and recorded average temperatures that ranged from -33°C (-27°F) in the afternoon, down to -86°C (-123°F) at night. Lander 2, located further to the north in a colder climate, soon photographed thin frosts caused by water vapour freezing out of the thin atmosphere.

One other experiment was perhaps the most fascinating of all. Each lander contained a biochemistry laboratory to carry out a series of tests to look for signs of microbes living in the Martian soil. These soon confirmed that Mars has all the elements necessary for so-called 'organic' chemistry, but a key question was whether something in the soil might be capable of taking chemical nutrients, processing them, and expelling waste products as gas. Identifying this sort of activity (which could indicate the presence of microbes) was the aim of the 'Labeled Release' experiment, which used radioactive elements to track atoms moving from nutrients to gas. Initial runs of the experiment came back positive from each lander, but a second test, a week later, produced nothing.

Scientists have argued over the meaning of these results ever since, and because more recent missions to Mars have had different priorities, the mystery remains unsolved. Viking Landers 1 and 2 continued to send back valuable data from Mars until 1982 and 1980 respectively before their batteries failed, but in one way, the final chapter in the story of these hugely successful probes has yet to be written. The search for potential life on Mars continues.

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# CELEBRATING VOYAGER

Over four decades ago, what would become two of NASA's most iconic spacecraft set off on a 'Grand Tour' of the Solar System… and they're still going strong

Written by Ben Gilliland

## Where are they now?

Data correct as of June 2019

**Voyager 1:**
**Distance from Earth:** 145 AU – 21.7 billion km
**Current speed:** 17km/s

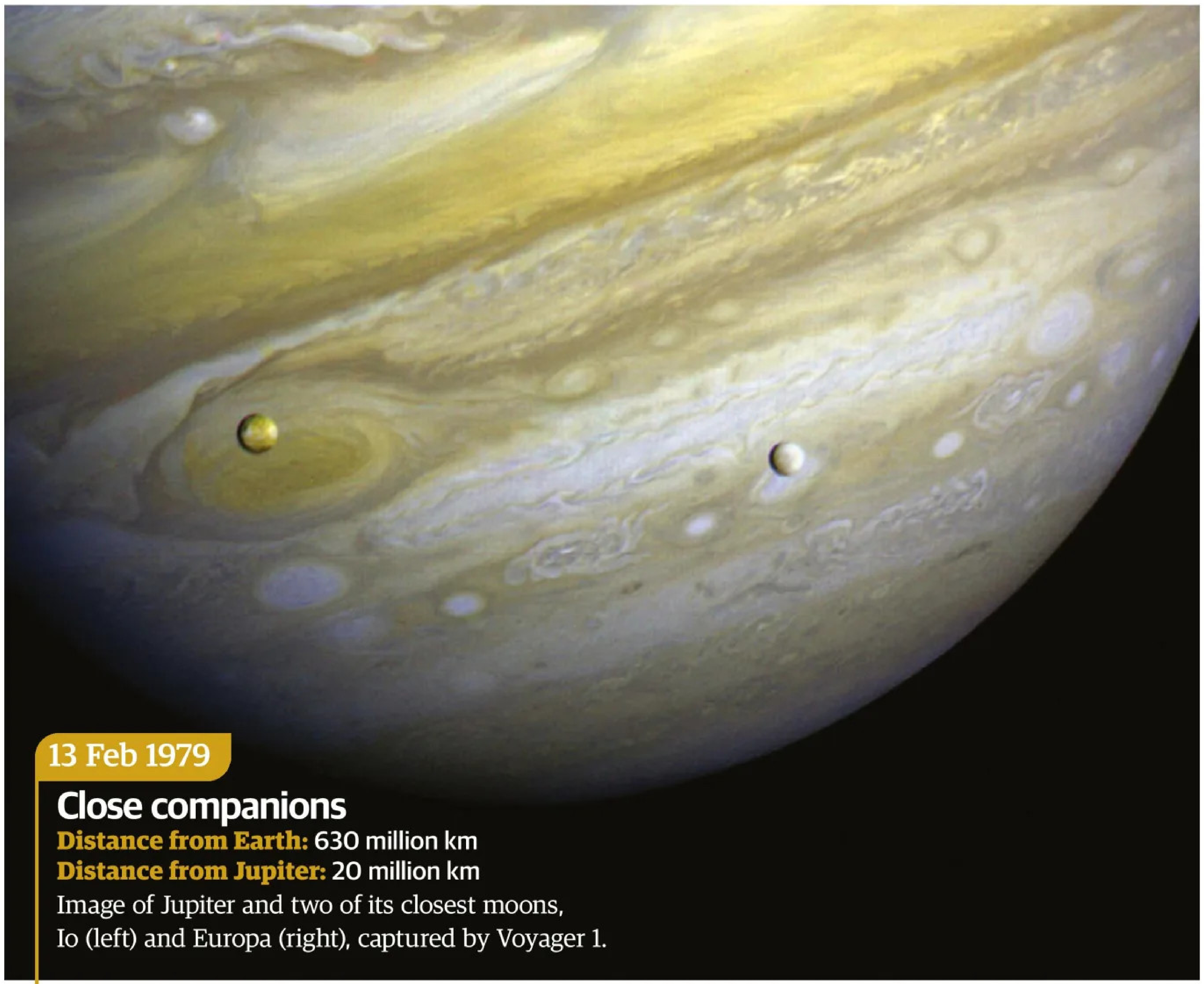
**Voyager 2:**
**Distance from Earth:** 120 AU – 18 billion km
**Current speed:** 15.4km/s

On 20 August 1977, a Titan-Centaur rocket blasted off from Cape Canaveral carrying NASA's Voyager 2 spacecraft. A little over two weeks later, Voyager 1 joined its twin on a mission to explore the Solar System. Over 40 years later, both craft are still boldly going where no spacecraft has gone before.

The Voyager mission, dubbed the 'Grand Tour', was designed to take advantage of an alignment of the Solar System's outer planets – Jupiter, Saturn, Uranus and Neptune – that takes place only once every 175 years. The alignment would allow the spacecraft to harness the gravity of each planet – swinging from one body to the next – gaining speed without expending vast amounts of fuel.

Despite launching later, Voyager 1 overtook its sibling in the asteroid belt between Mars and Jupiter. By November 1980, Voyager 1 had completed its primary mission of visiting Jupiter and Saturn and, using the ringed-giant's gravity it set a course for interstellar space. Lagging behind, Voyager 2 continued on to study Uranus and Neptune – arriving at Neptune in 1989. The first spacecraft to visit the outer planets, Voyager 2's mission revealed a surprising cosmic neighbourhood. Neptune, so far from the Sun's energy and thought to be cold and quiet, was found to be a maelstrom of atmospheric turbulence; and moons, thought to be dead, were found to be churning with geological activity.

By this point, both spacecraft, which were designed to last just five years, were well out of their warranties, but still they continued on. Today, four decades after they launched, more than 17 billion kilometres from Earth, and with many of their systems shut down to conserve energy, both craft have the Solar System in their rear-view mirrors and are cruising toward interstellar space.



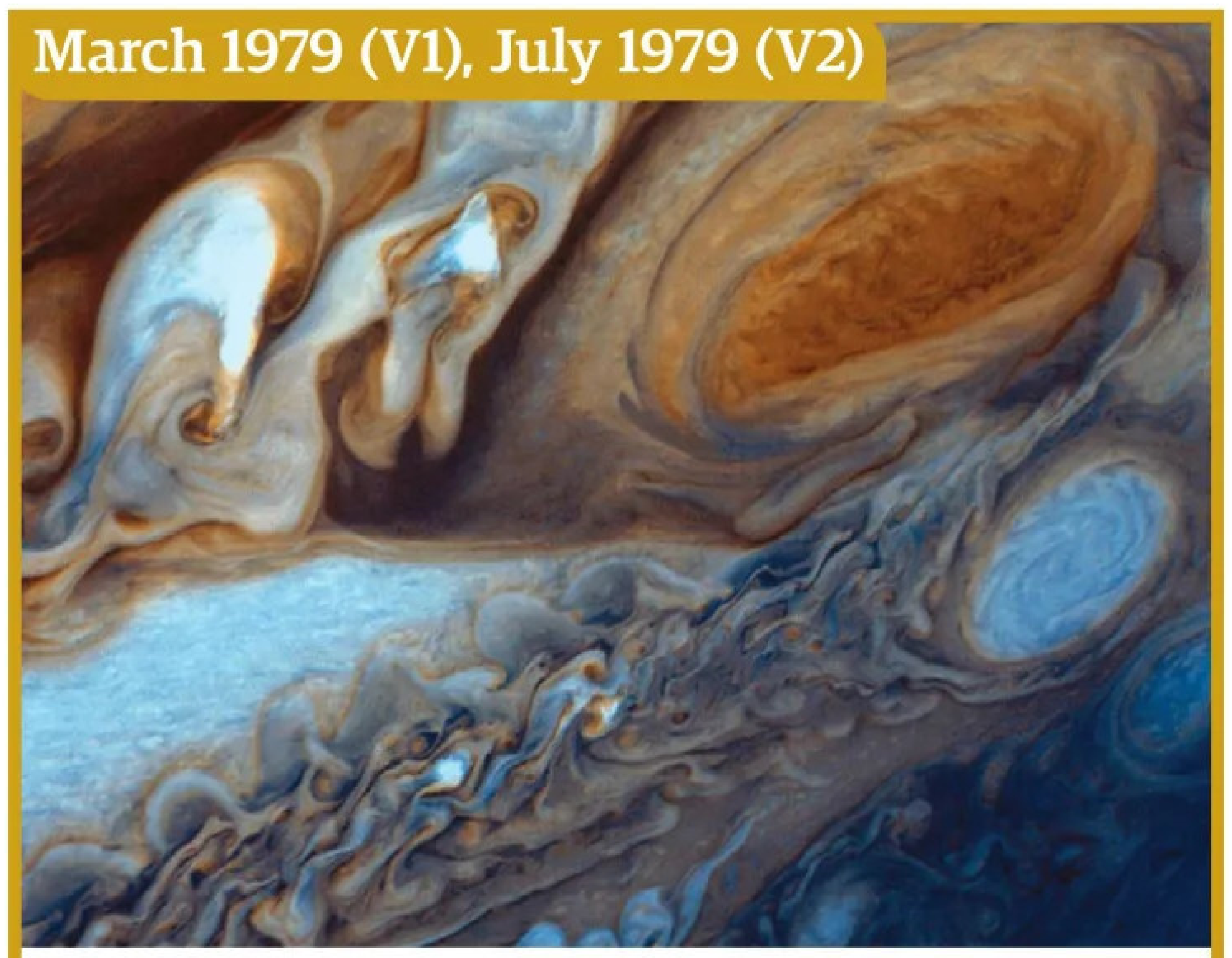
13 Feb 1979

## Close companions

**Distance from Earth:** 630 million km
**Distance from Jupiter:** 20 million km

Image of Jupiter and two of its closest moons, Io (left) and Europa (right), captured by Voyager 1.

March 1979 (V1), July 1979 (V2)



## Jupiter's turbulent atmosphere and Great Red Spot

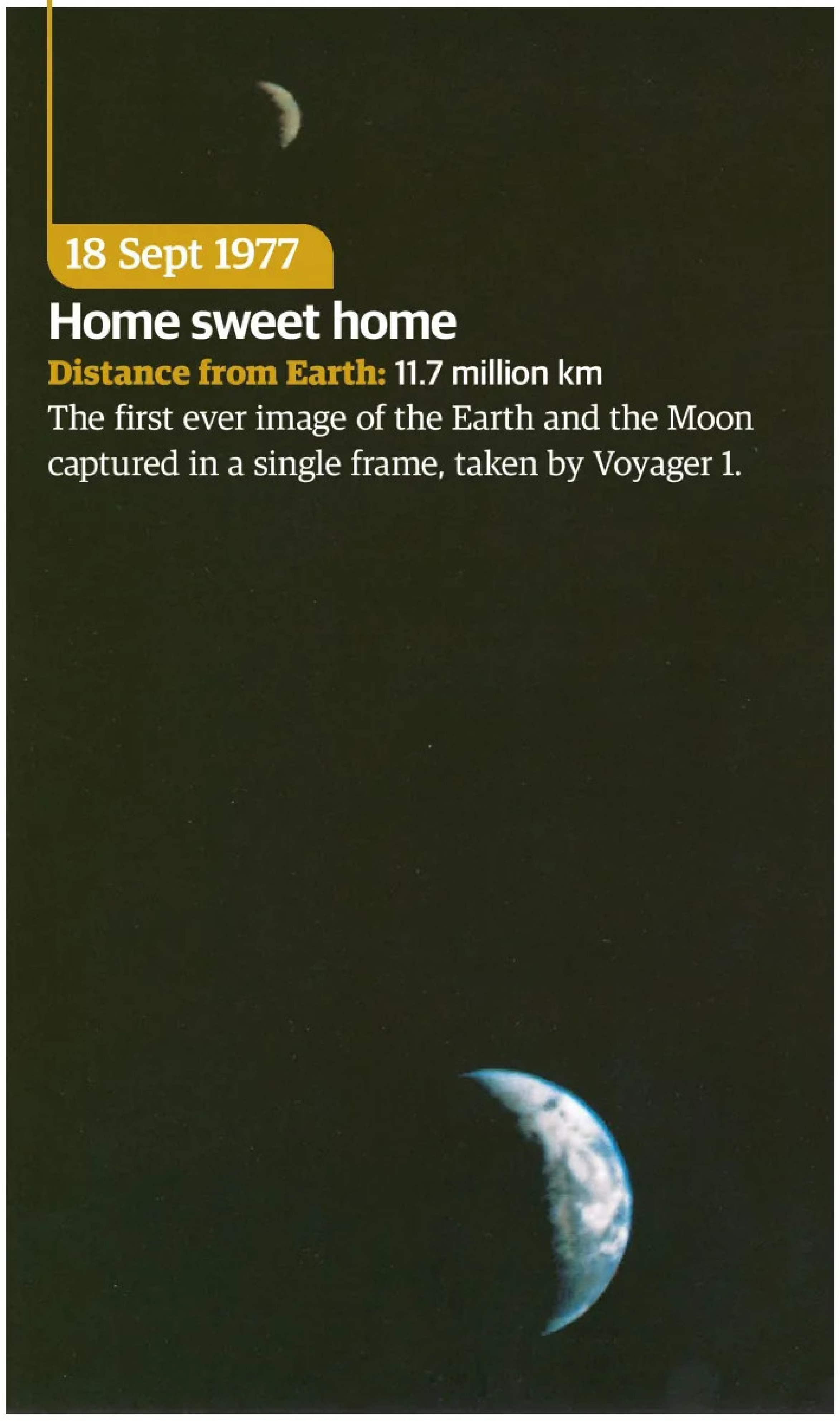
**Distance from Earth:** 650 million km
**Distance from Jupiter:** 348,890km
(V1 closest approach)

Voyager 1 began its Jupiter observation phase in January 1979, Voyager 2 arrived four months later. They revealed Jupiter's atmosphere to be a gaseous maelstrom – with dozens of hurricane-like storms interacting throughout the planet's banded cloud systems. The gas giant's famous 'Great Red Spot' was shown to be a complex storm moving in a counterclockwise direction.

1977

1978

1979



18 Sept 1977

## Home sweet home

**Distance from Earth:** 11.7 million km

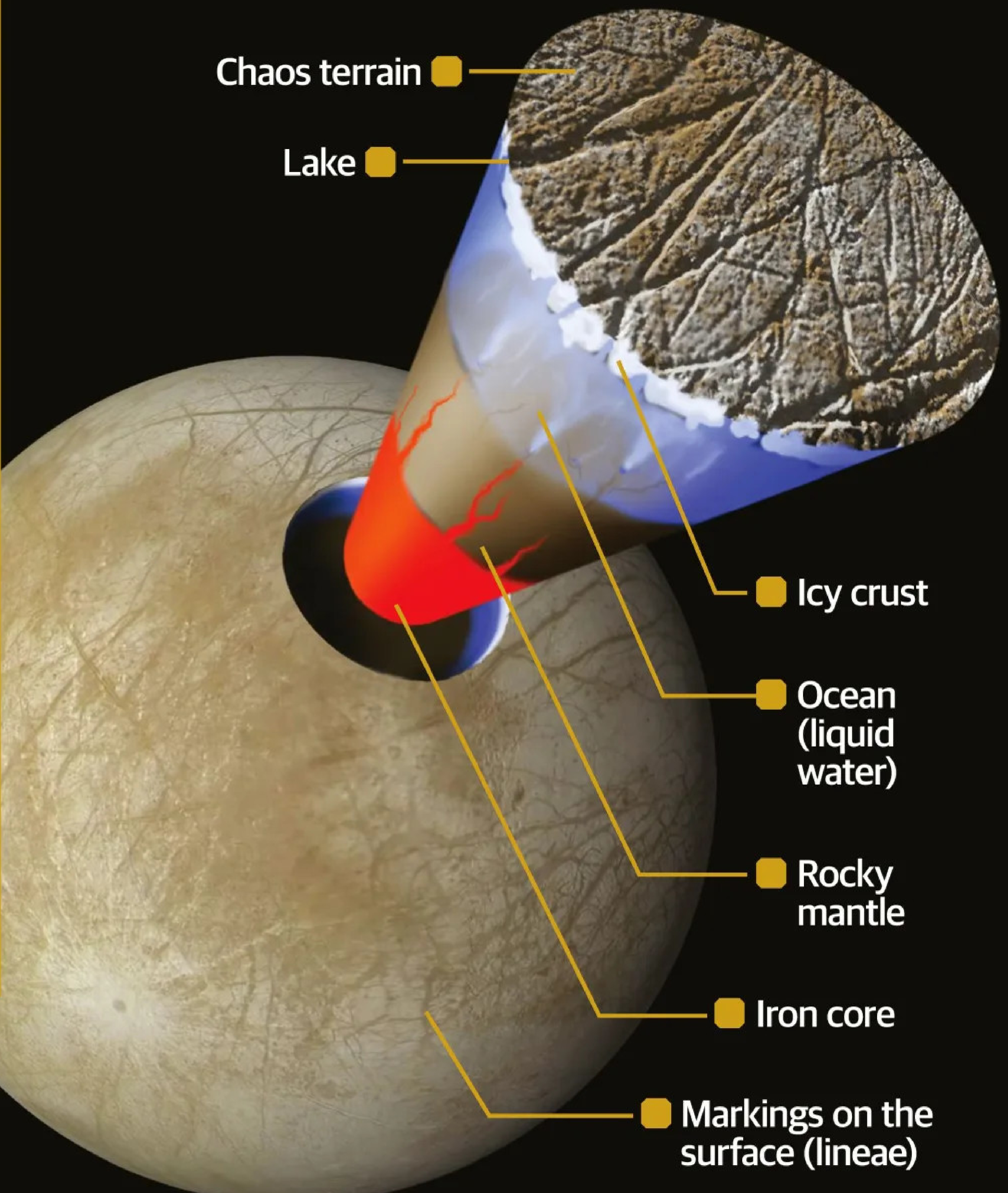
The first ever image of the Earth and the Moon captured in a single frame, taken by Voyager 1.

5 March 1979 (V1), 9 July 1979 (V2)

## The hidden oceans of Europa

**Distance from Europa:** 205,720km
(V2 closest approach)

The first images sent back by Voyager 1 of Jupiter's sixth moon, Europa, showed a number of intriguing linear features, resembling surface cracks, that intersected the moon's surface. Later, hi-resolution photographs taken from much closer by Voyager 2, revealed a surface almost entirely bereft of impact craters – suggesting that some sort of internal process, such as icy volcanic flows from a subterranean ocean, was actively erasing them.



March 1979 (V1), July 1979 (V2)

## Jupiter's delicate system of rings

**Distance from Jupiter:** 348,890km (V1 closest approach)

Although by far the most famous, Saturn is not the only gas giant with a ring system. As it skirted past Jupiter (stealing a bit of momentum from its gravitational field as it did so), Voyager 1 detected a delicate system of dusty rings – thought to be created by dust kicked into space by impacts on its small moons.

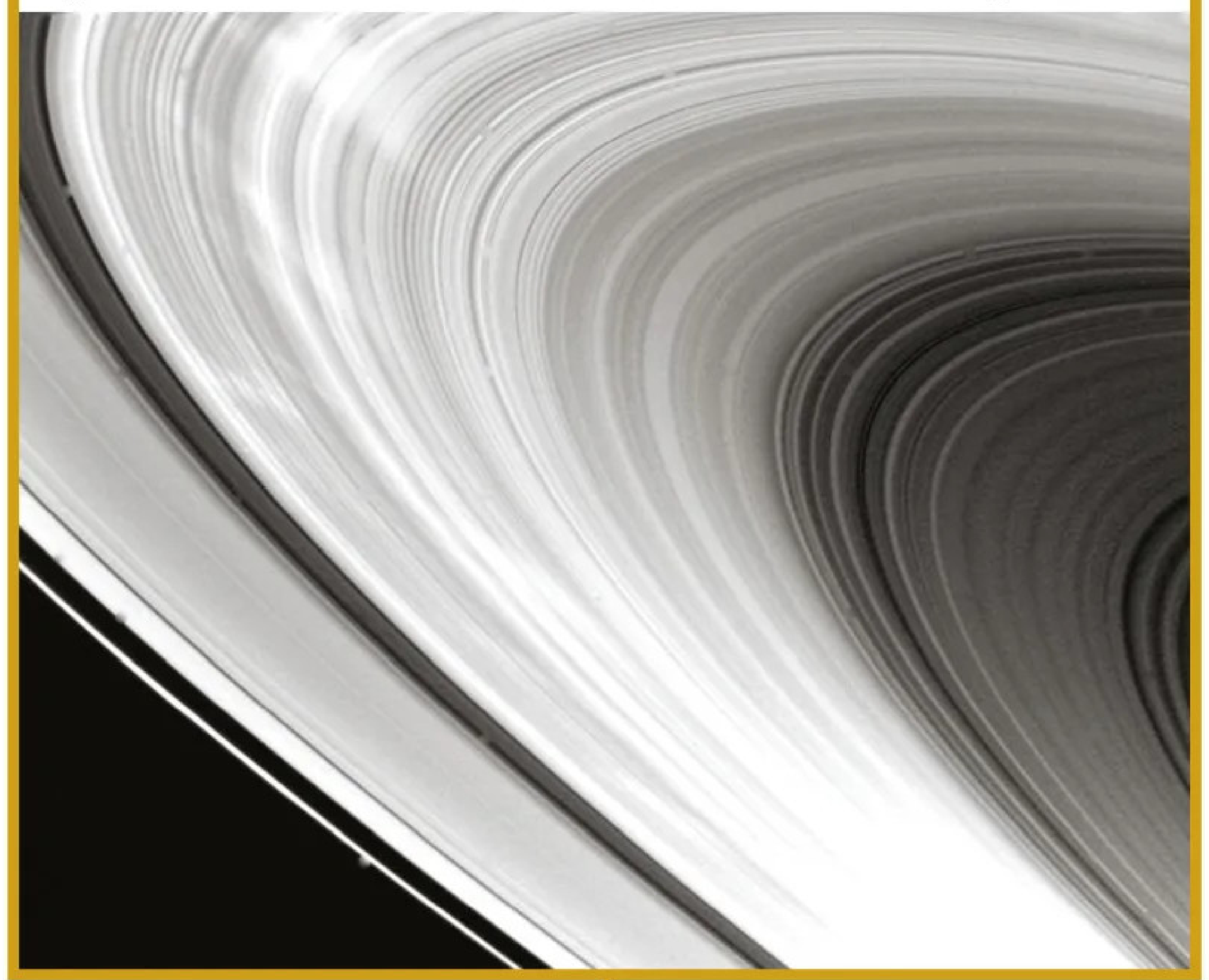
November 1980 (V1), August 1981 (V2)

## The complex beauty of Saturn's rings

**Distance from Saturn:** 161,000km (V2 closest approach)

**Distance from Earth:** 1.3 billion km

The Voyager spacecraft provided the first close-up look at the gas giant's icy rings. The images they sent home revealed a complex system of waves and fine structures caused by the tug of nearby moons. Instead of the six visible from Earth, scientists counted over 100 separate rings. They also discovered small 'shepherd' moons whose gravitational influence stabilises and herds the rings.



12 November 1980 (V1), 25 August 1981 (V2)

## The blanketing clouds of Titan

**Distance from Titan:** 6,490km (V1 closest approach)

For centuries, Titan's thick, opaque atmosphere had scientists believing it was the Solar System's largest moon (hence its name), but Voyager's measurements showed the moon to be slightly smaller than Jupiter's Ganymede. Its dense atmosphere still prevented Voyager from seeing the moon's surface, but measurements of its composition showed that it may possess a similar chemistry to Earth's own atmosphere billions of years ago. It also led to speculation that there may be lakes of liquid hydrocarbons on its surface.

1979

1980

1981

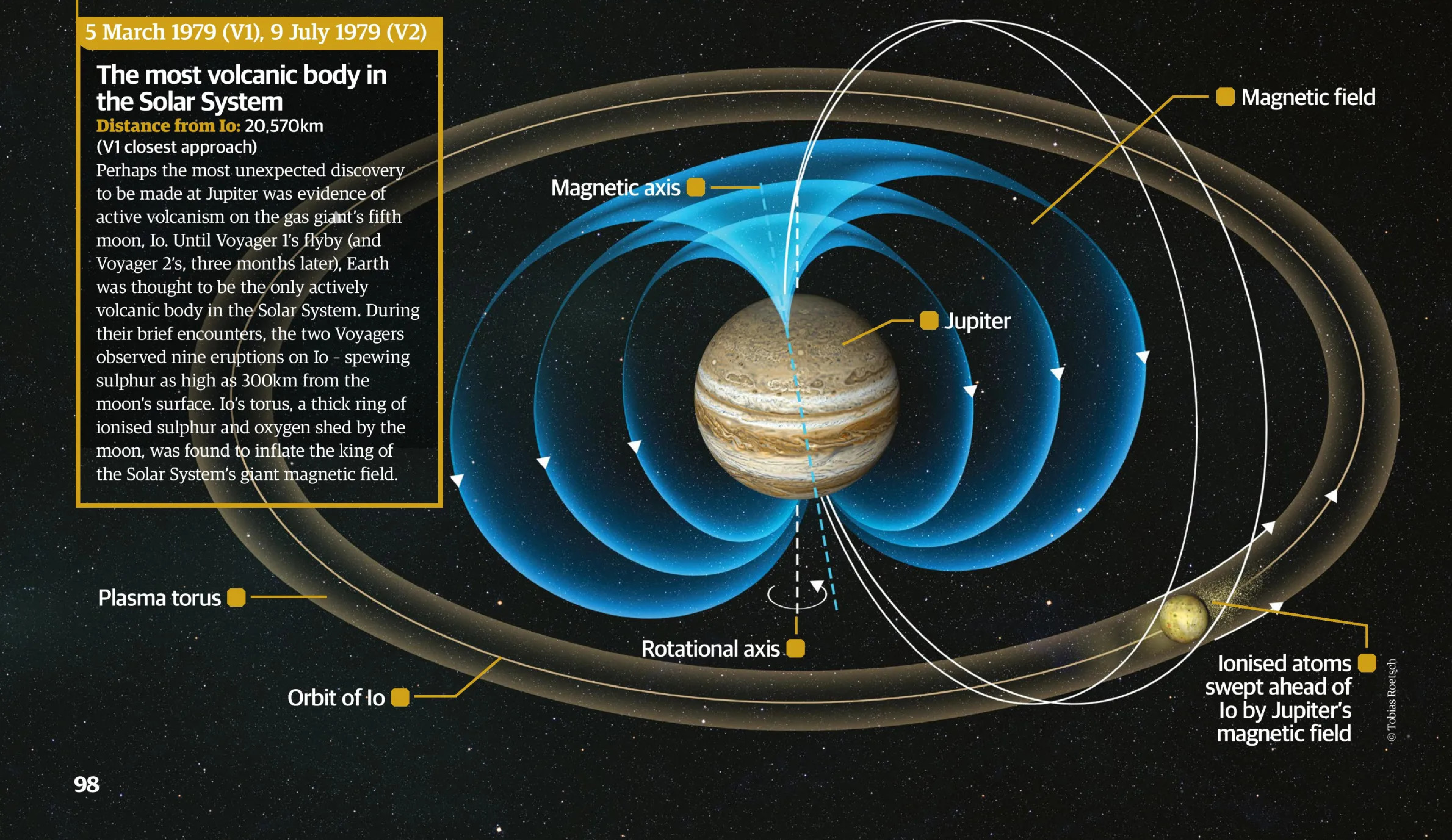
1982

5 March 1979 (V1), 9 July 1979 (V2)

## The most volcanic body in the Solar System

**Distance from Io:** 20,570km (V1 closest approach)

Perhaps the most unexpected discovery to be made at Jupiter was evidence of active volcanism on the gas giant's fifth moon, Io. Until Voyager 1's flyby (and Voyager 2's, three months later), Earth was thought to be the only actively volcanic body in the Solar System. During their brief encounters, the two Voyagers observed nine eruptions on Io – spewing sulphur as high as 300km from the moon's surface. Io's torus, a thick ring of ionised sulphur and oxygen shed by the moon, was found to inflate the king of the Solar System's giant magnetic field.



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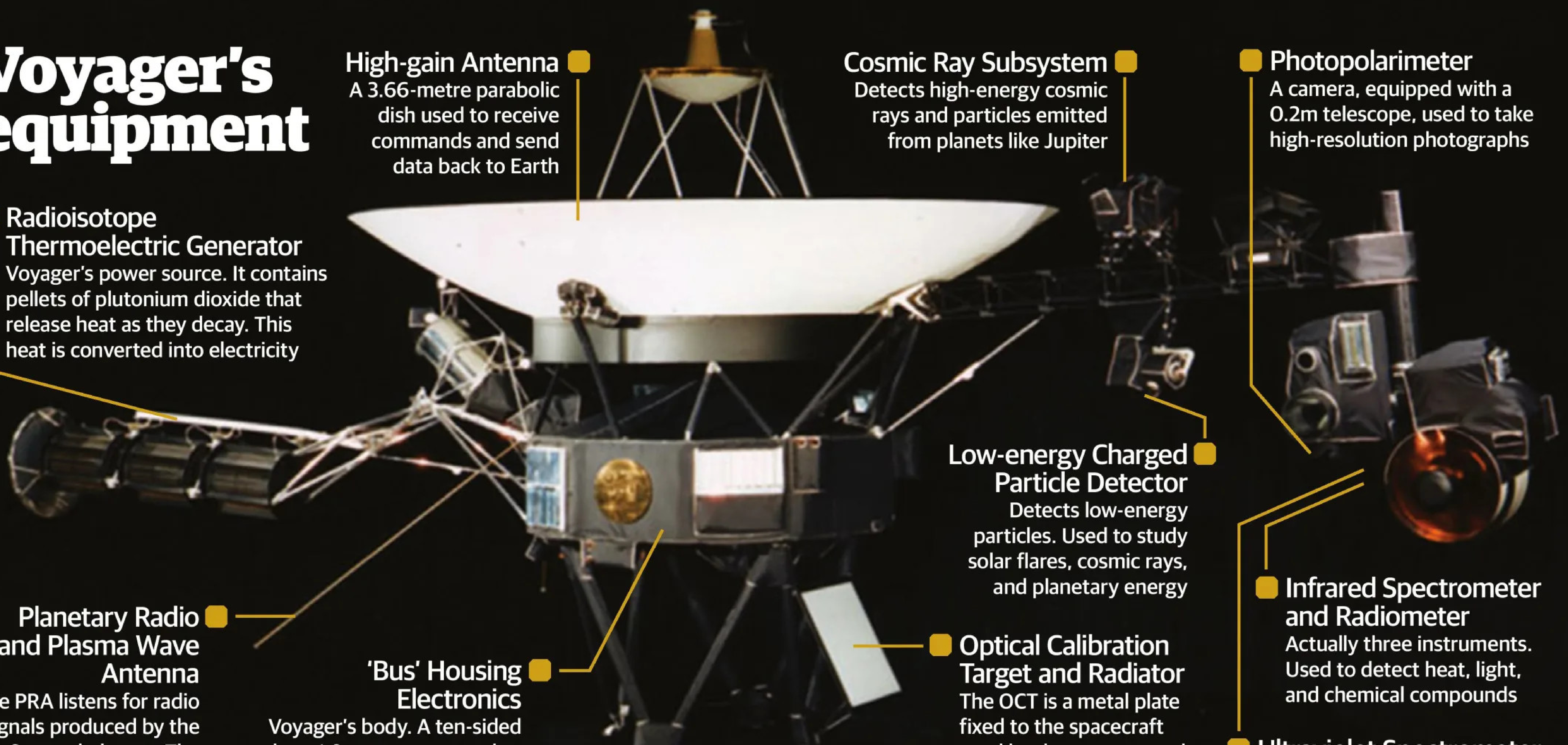
# Voyager's equipment



**Radioisotope Thermoelectric Generator**
Voyager's power source. It contains pellets of plutonium dioxide that release heat as they decay. This heat is converted into electricity

**High-gain Antenna**
A 3.66-metre parabolic dish used to receive commands and send data back to Earth

**Cosmic Ray Subsystem**
Detects high-energy cosmic rays and particles emitted from planets like Jupiter

**Photopolarimeter**
A camera, equipped with a 0.2m telescope, used to take high-resolution photographs

**Low-energy Charged Particle Detector**
Detects low-energy particles. Used to study solar flares, cosmic rays, and planetary energy

**Planetary Radio and Plasma Wave Antenna**
The PRA listens for radio signals produced by the Sun and planets. The PWA 'listens' for plasma oscillations caused by energetic events

**'Bus' Housing Electronics**
Voyager's body. A ten-sided box, 1.8 metres across, that contains some scientific instruments, electronics and a fuel tank for the thrusters

**Optical Calibration Target and Radiator**
The OCT is a metal plate fixed to the spacecraft used by the cameras and detectors for calibration. The radiator vents excess heat into space

**Infrared Spectrometer and Radiometer**
Actually three instruments. Used to detect heat, light, and chemical compounds

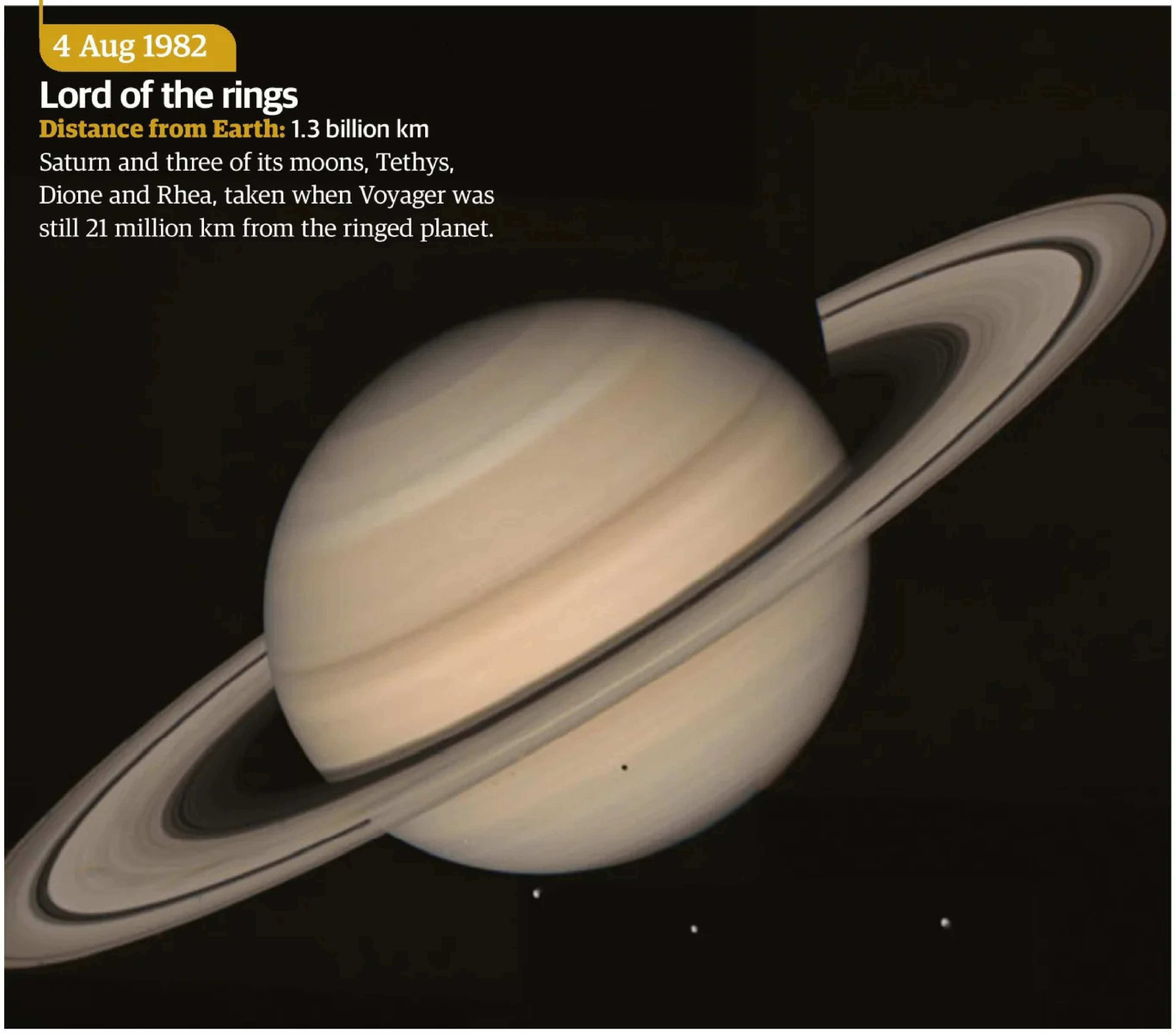
**Ultraviolet Spectrometer**
This detects ultraviolet light. It is used to study a planet's atmosphere

1983

1984

1985

1986



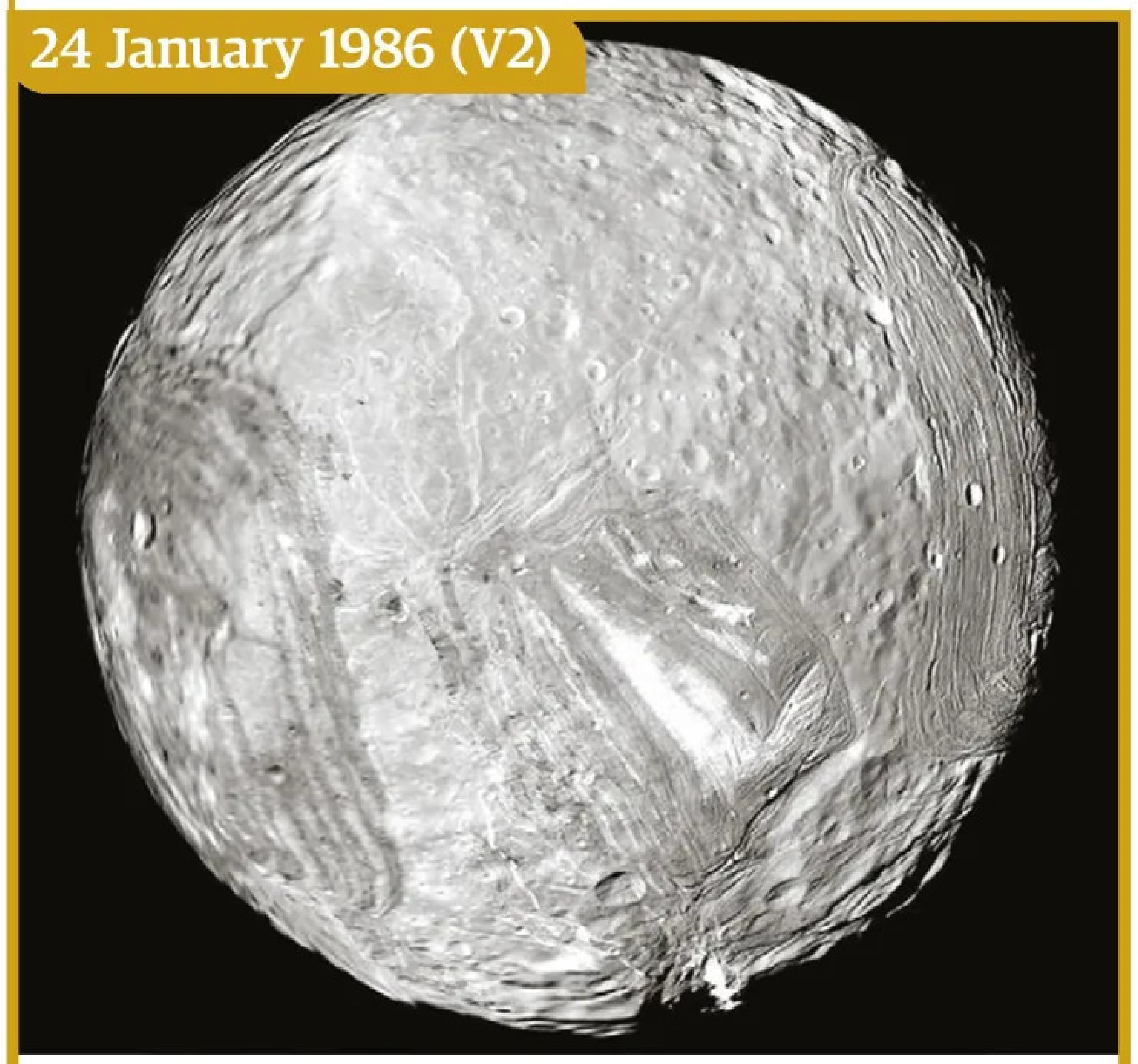
4 Aug 1982

### Lord of the rings

**Distance from Earth:** 1.3 billion km

Saturn and three of its moons, Tethys, Dione and Rhea, taken when Voyager was still 21 million km from the ringed planet.

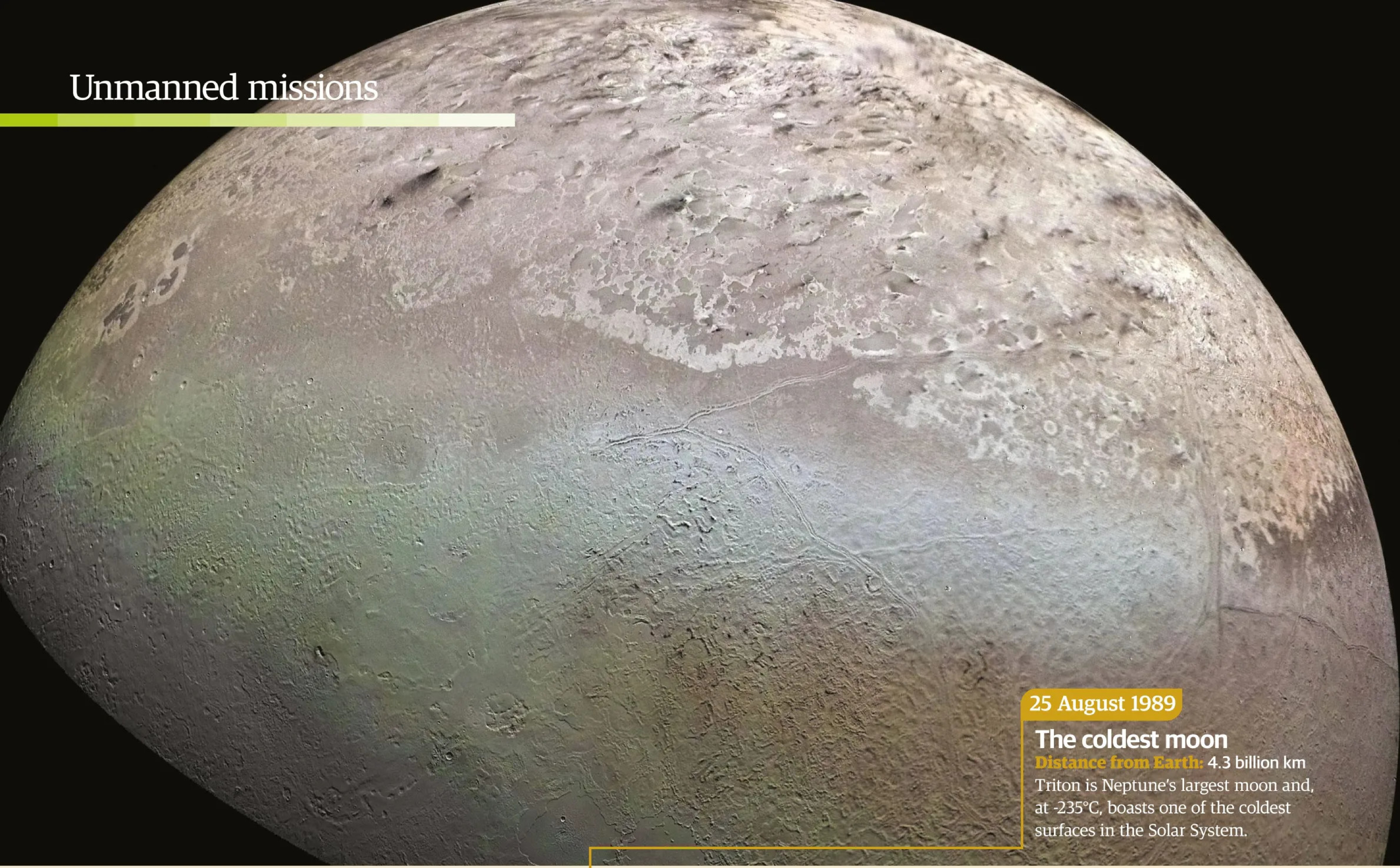
24 January 1986 (V2)



### The 'strangest' moon in the Solar System

**Distance from Miranda:** 31,000km (V2 closest approach)

As well as discovering 11 previously unknown Uranian moons, Voyager 2 also revealed the innermost of Uranus' moons, Miranda, to be one of the strangest bodies in the Solar System. Voyager's images showed that the moon's surface is scarred by huge 20 kilometre-deep canyons, which suggest that the moon may have been torn apart in its past and then reformed from the shattered remains.



25 August 1989

### The coldest moon

**Distance from Earth:** 4.3 billion km
Triton is Neptune's largest moon and, at -235°C, boasts one of the coldest surfaces in the Solar System.

1986 1987 1988 1989 1990 1991 1992 1993 1994 1995

24 January 1986 (V2)

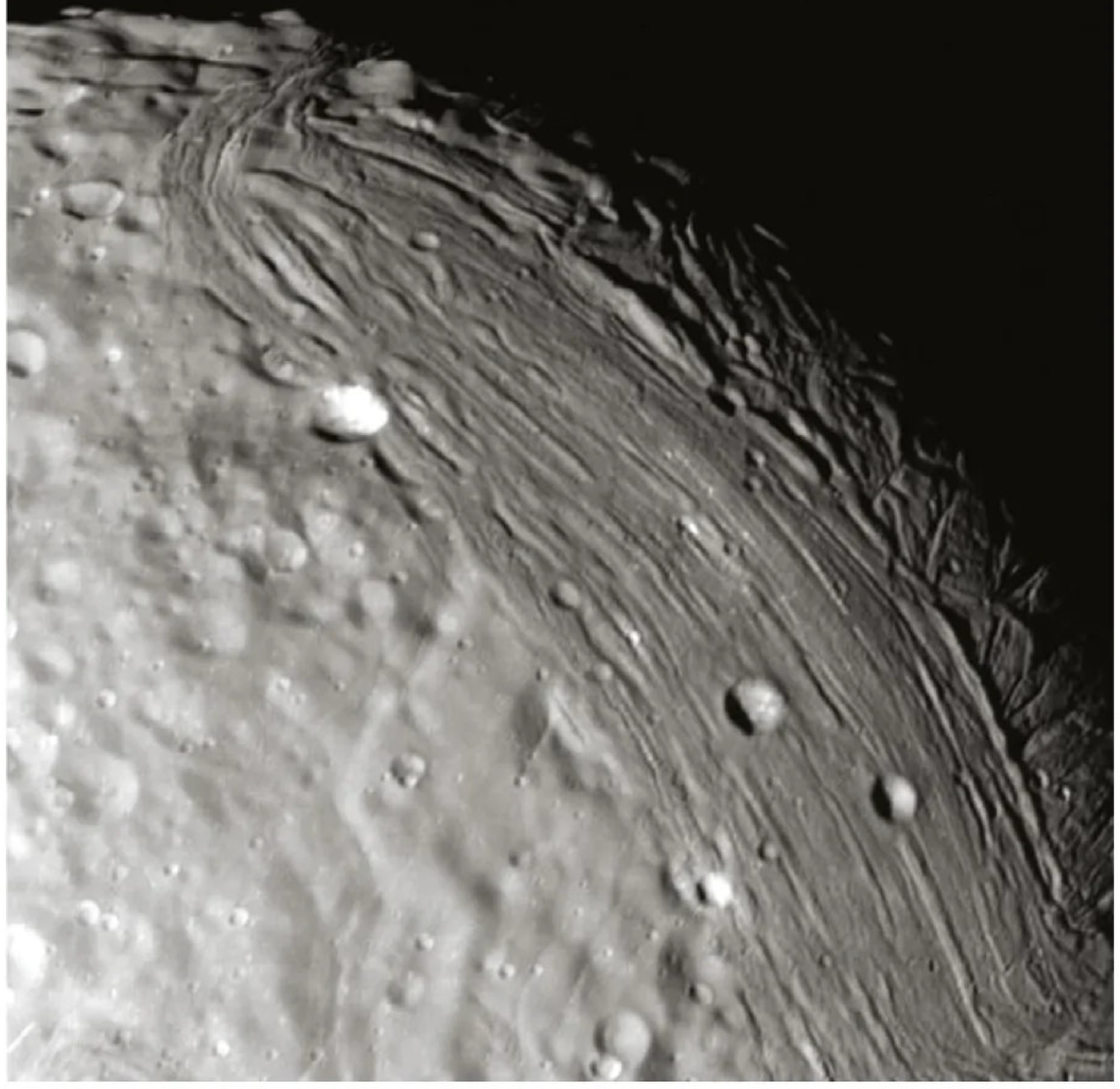
### Uranus' 'twisted' magnetism

**Distance from Uranus:** 107,000km (V2 closest approach)
**Distance from Earth:** 3 billion km
While Voyager 1 headed out into deep space, Voyager 2 continued its planetary tour by visiting the 'lop-sided' ice giant, Uranus, which is tilted on its axis by 98 degrees. Voyager 2 discovered that this sideways tilt has a very strange effect on the planet's magnetic field – twisting it into a sort of corkscrew shape that trails some 10 million km behind the planet.

24 January 1986

### Scarred Miranda

**Distance from Earth:** 4.6 billion km
The deep scars and varied terrain on Uranus' moon, Miranda, suggests a complex, and possibly violent, geological history.

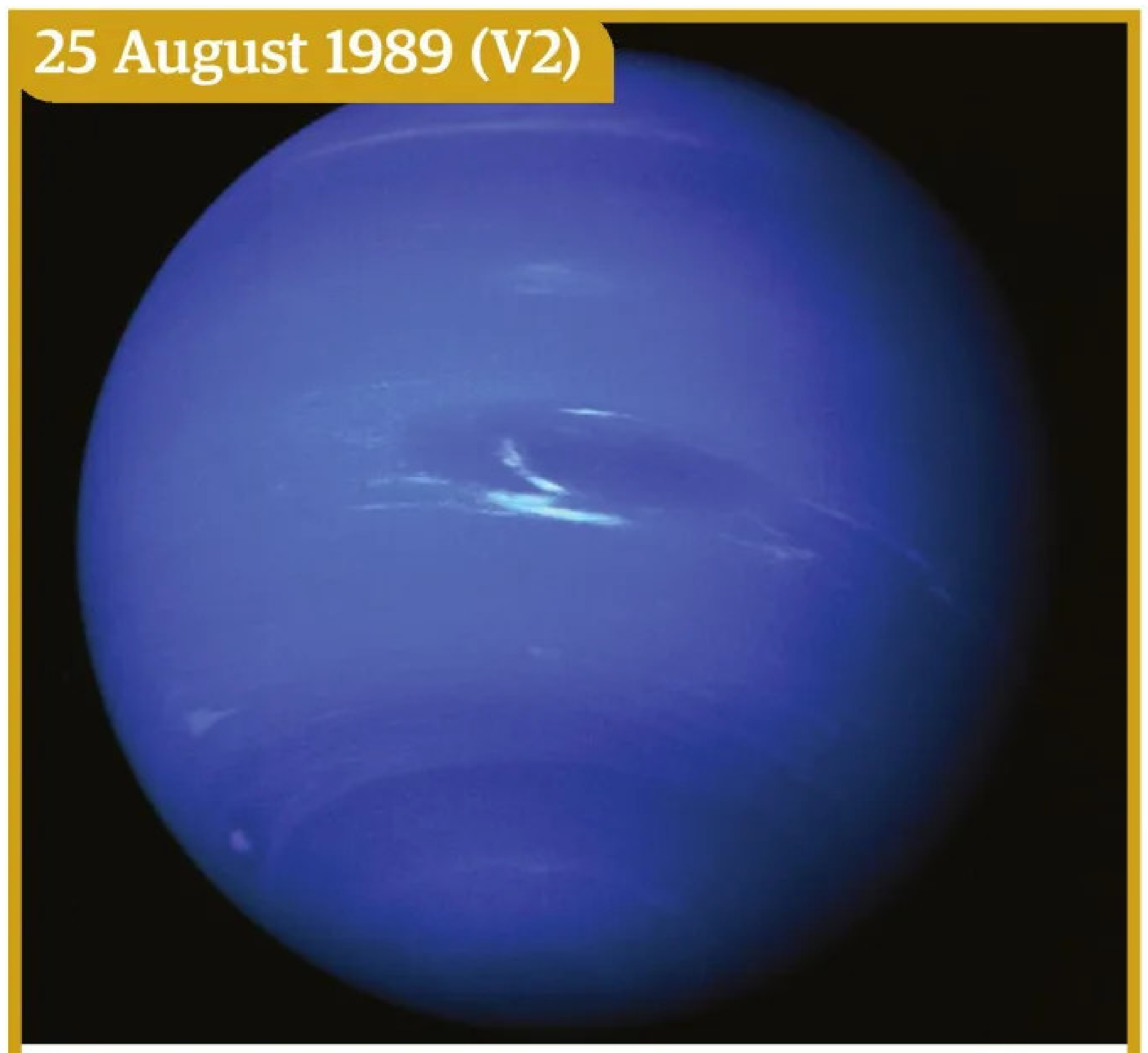


25 Jan 1986

### Goodbye, Uranus

**Distance from Earth:** 3 billion km
A farewell shot of a crescent Uranus taken by Voyager 2, from a distance of 965,000km, as it departed for Neptune.

25 August 1989 (V2)

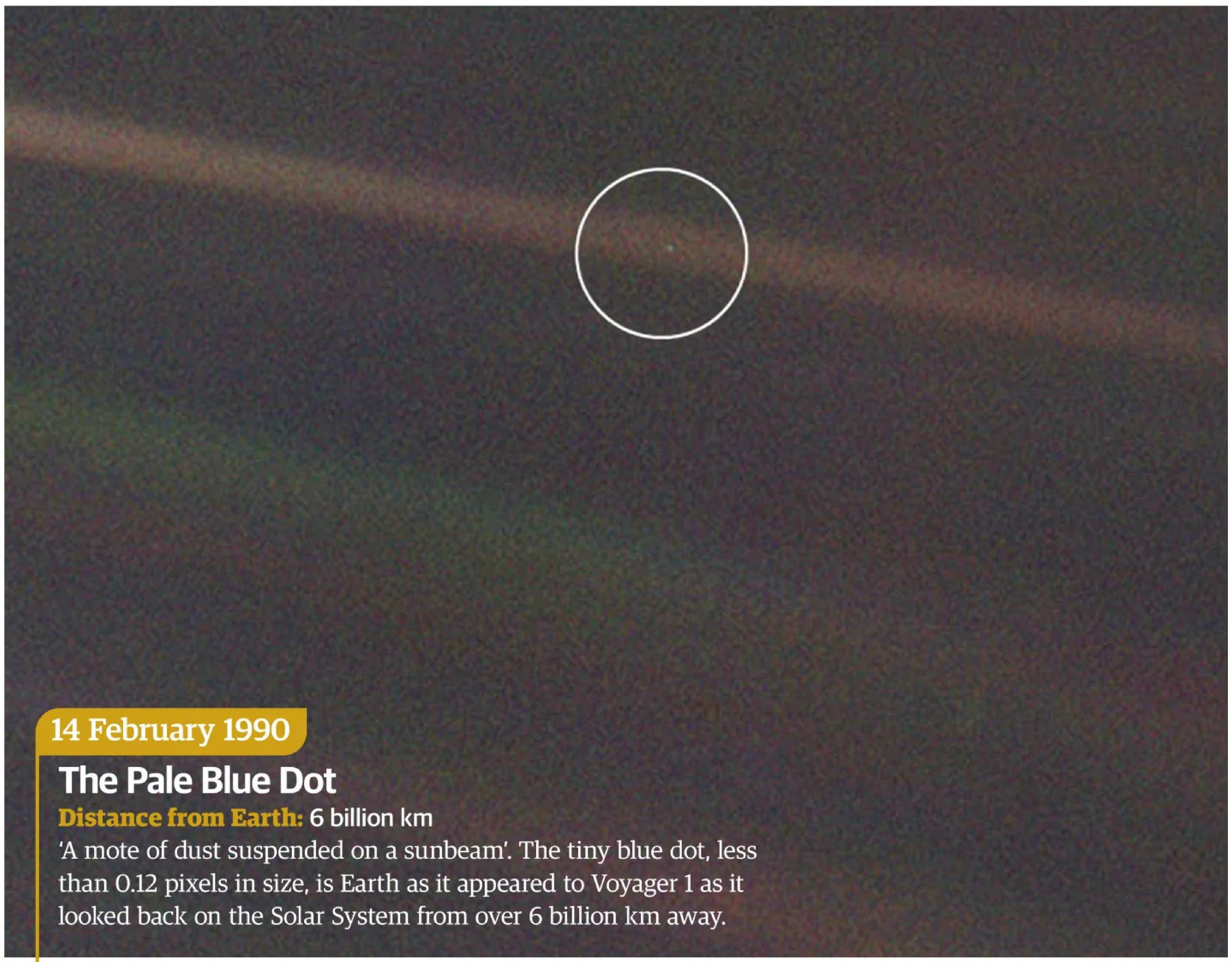


### Neptune's 'Great Dark Spot'

**Distance from Neptune:** 4,950km (V2 closest approach)

**Distance from Earth:** 4.6 billion km

Voyager 2 gave humanity its first glimpse of Neptune and its moon Triton. It discovered the 'Great Dark Spot' – a large dark blue smudge the size of Earth. At first thought to be a large cloud, the spot was actually a storm system, similar to Jupiter's Red Spot, whose 2,400km/h winds carved a hole in Neptune's methane cloud deck – revealing the darker blue beneath.

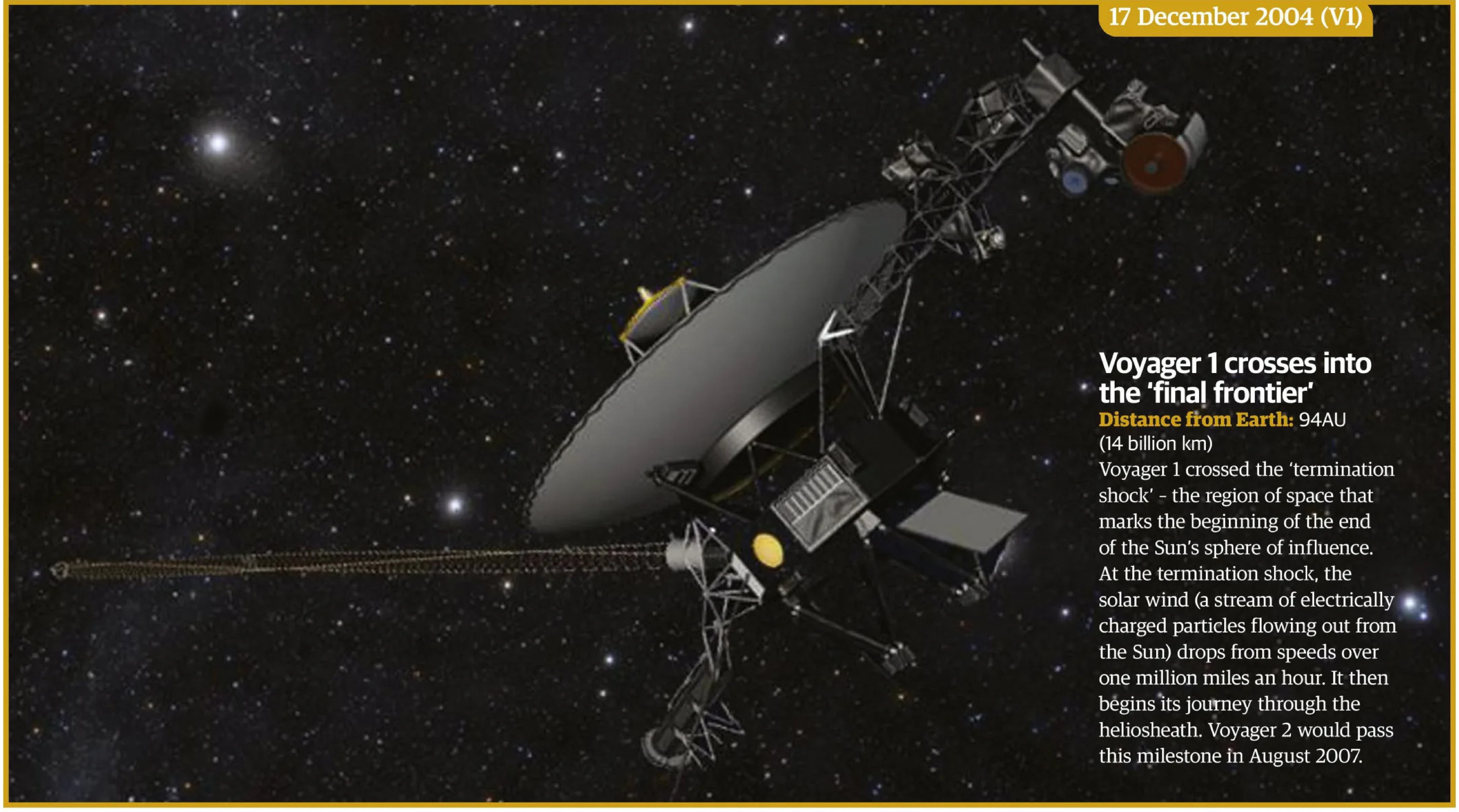


14 February 1990

### The Pale Blue Dot

**Distance from Earth:** 6 billion km

'A mote of dust suspended on a sunbeam'. The tiny blue dot, less than 0.12 pixels in size, is Earth as it appeared to Voyager 1 as it looked back on the Solar System from over 6 billion km away.

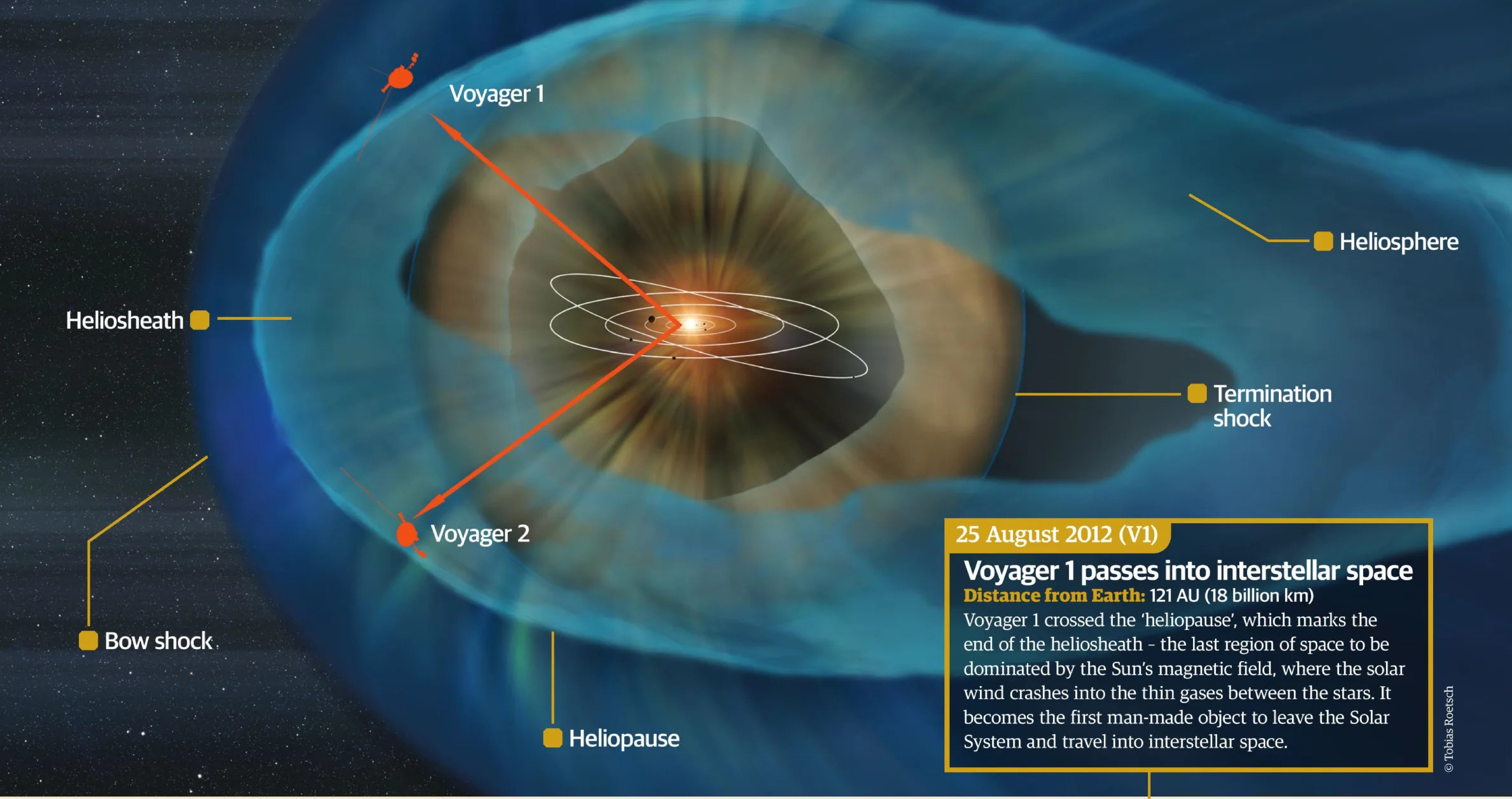


17 December 2004 (V1)

### Voyager 1 crosses into the 'final frontier'

**Distance from Earth:** 94AU (14 billion km)

Voyager 1 crossed the 'termination shock' – the region of space that marks the beginning of the end of the Sun's sphere of influence. At the termination shock, the solar wind (a stream of electrically charged particles flowing out from the Sun) drops from speeds over one million miles an hour. It then begins its journey through the heliosheath. Voyager 2 would pass this milestone in August 2007.



© Tobias Roetsch

25 August 2012 (V1)

### Voyager 1 passes into interstellar space

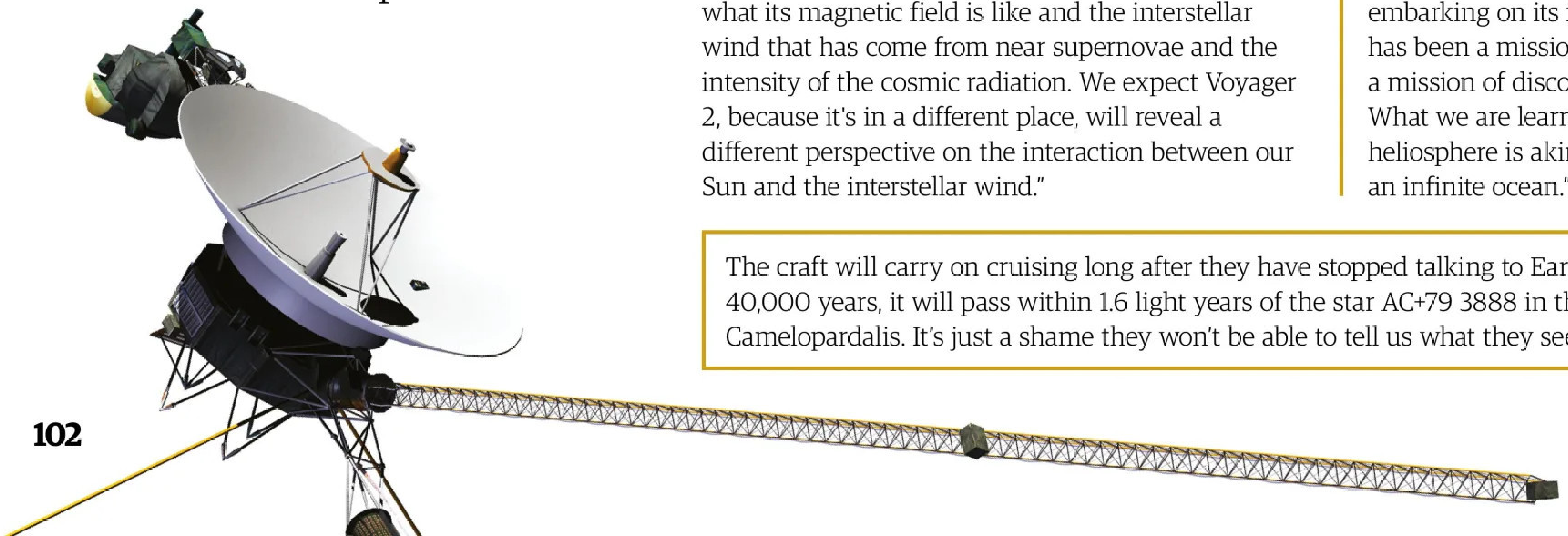
**Distance from Earth:** 121 AU (18 billion km)

Voyager 1 crossed the 'heliopause', which marks the end of the heliosheath – the last region of space to be dominated by the Sun's magnetic field, where the solar wind crashes into the thin gases between the stars. It becomes the first man-made object to leave the Solar System and travel into interstellar space.

2012 2013 2014 2015 2016 2017 FUTURE

# What's next for Voyager?

Voyager's radioactive power packs will continue to provide power until about 2025. Until then (by which time Voyager is expected to be about 22.6 billion kilometres from home), they will continue to send data about the interstellar environment back to Earth. Voyager's scientists have high hopes that the Voyagers still have discoveries hidden up their sleeves.



**Ed Stone**

**VOYAGER PROJECT SCIENTIST**

"We hope to learn more about the Milky Way galaxy: what its magnetic field is like and the interstellar wind that has come from near supernovae and the intensity of the cosmic radiation. We expect Voyager 2, because it's in a different place, will reveal a different perspective on the interaction between our Sun and the interstellar wind."

**Suzy Dodd**

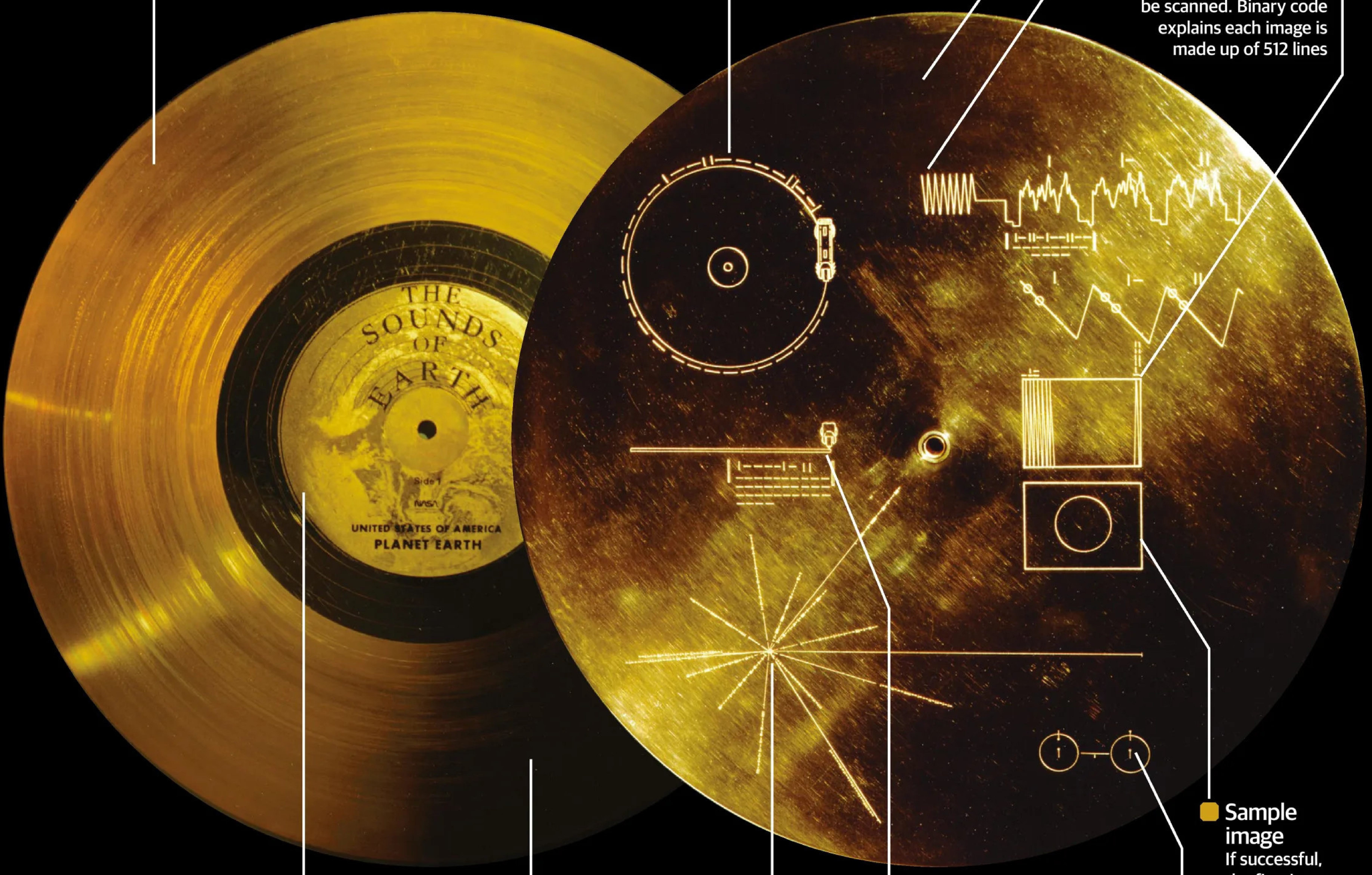
**VOYAGER PROJECT MANAGER**

"Having a spacecraft built to last four years now embarking on its fifth decade is incredible. Voyager has been a mission of discovery. It continues to be a mission of discovery even in interstellar space. What we are learning about what is beyond our heliosphere is akin to being just over the horizon of an infinite ocean."

The craft will carry on cruising long after they have stopped talking to Earth and, in about 40,000 years, it will pass within 1.6 light years of the star AC+79 3888 in the constellation Camelopardalis. It's just a shame they won't be able to tell us what they see out there.

# Voyager's Golden Record

On the off-chance that the Voyagers encountered aliens during their extended travels, both craft are equipped with identical 12-inch phonograph records for ET to decode



**The playback side**
This side contains the images and audio recording for the alien to playback and decode

**Overhead diagram of the record**
Shows the alien how to correctly place the stylus. Binary code explains the record's playback speed (3.6 seconds per rotation)

**The instructions side**
This side contains instructions explaining how to play the record's audio and extract the images

**How to view the images**
Wavelength diagrams illustrate how the images are made up of analogue video signals. Binary explains each scan lasts eight milliseconds

**Direction of scan**
Diagram showing the direction the images should be scanned. Binary code explains each image is made up of 512 lines

**Sample image**
If successful, the first image extracted should match this one

**Sounds of Earth**
Along with a selection of music, there are greetings in 55 languages and sounds from nature – including a brief hello from some humpback whales

**Sights of Earth**
Encoded along with the audio are 115 pictures of Earth, the Solar System and various plants and animals

**Side-view of the record**
Binary code shows that the record takes one hour to play back

**How to find Earth**
A map showing the location of 14 pulsars relative to Earth (centre). Binary code gives the frequency of each pulsar

**Hydrogen diagram**
Shows the two lowest states of a hydrogen atom. The transition time between states is used to decode the images on record

© ESO; J. Emerson; NASA; JPL; Carla Cioffi; Getty Images; Ron Miller

# *WHAT'S NEXT FOR* HUBBLE?

The long-serving space telescope has been observing the universe for over 30 years. What's next on its horizon could lead to even more groundbreaking discoveries

Written by Lee Cavendish

When the Hubble Space Telescope was launched on 24 April 1990, no one thought it would last as long as it has. NASA and the European Space Agency (ESA) had collaborated to create a groundbreaking, audacious space telescope, but it didn't rise to prominence without its hiccups. Initially scheduled to launch in October 1986, the tragic loss of Challenger in January 1986 forced the agencies to postpone Hubble's launch by four years.

When the launch date finally came around, the long-awaited Hubble Space Telescope flew on board the Space Shuttle Discovery (STS-31). Discovery positioned Hubble at an altitude of 569 kilometres (353 miles) over our heads. At last the telescope was ready, and astronomers couldn't wait to feast their eyes upon the wonders of the universe it could reveal. But, unfortunately, there was another setback...

Astronomers were hoping to view the most crisp, clear and incredible images of galaxies and nebulae. Instead, they were saddened by the return of blurry and out-of-focus images. An incorrectly installed null corrector led to a lens being out of focus by 1.3mm (0.051 inches), almost resulting in a $4.7 billion (approximately £3.4 billion) white elephant. However, with some creative thinking, corrective optics were installed on the first servicing mission in 1993, and astronomers could finally marvel at its majestic images and insightful data.

After four more servicing missions, the last in 2009, Hubble has been a picture of health. "Since the execution of Servicing Mission 4 in 2009, Hubble has been operating at its peak in terms of science productivity, and astronomers' interest remains at an all-time high now almost 30 years after its launch," explains Patrick Crouse, project manager of the Hubble Space Telescope.

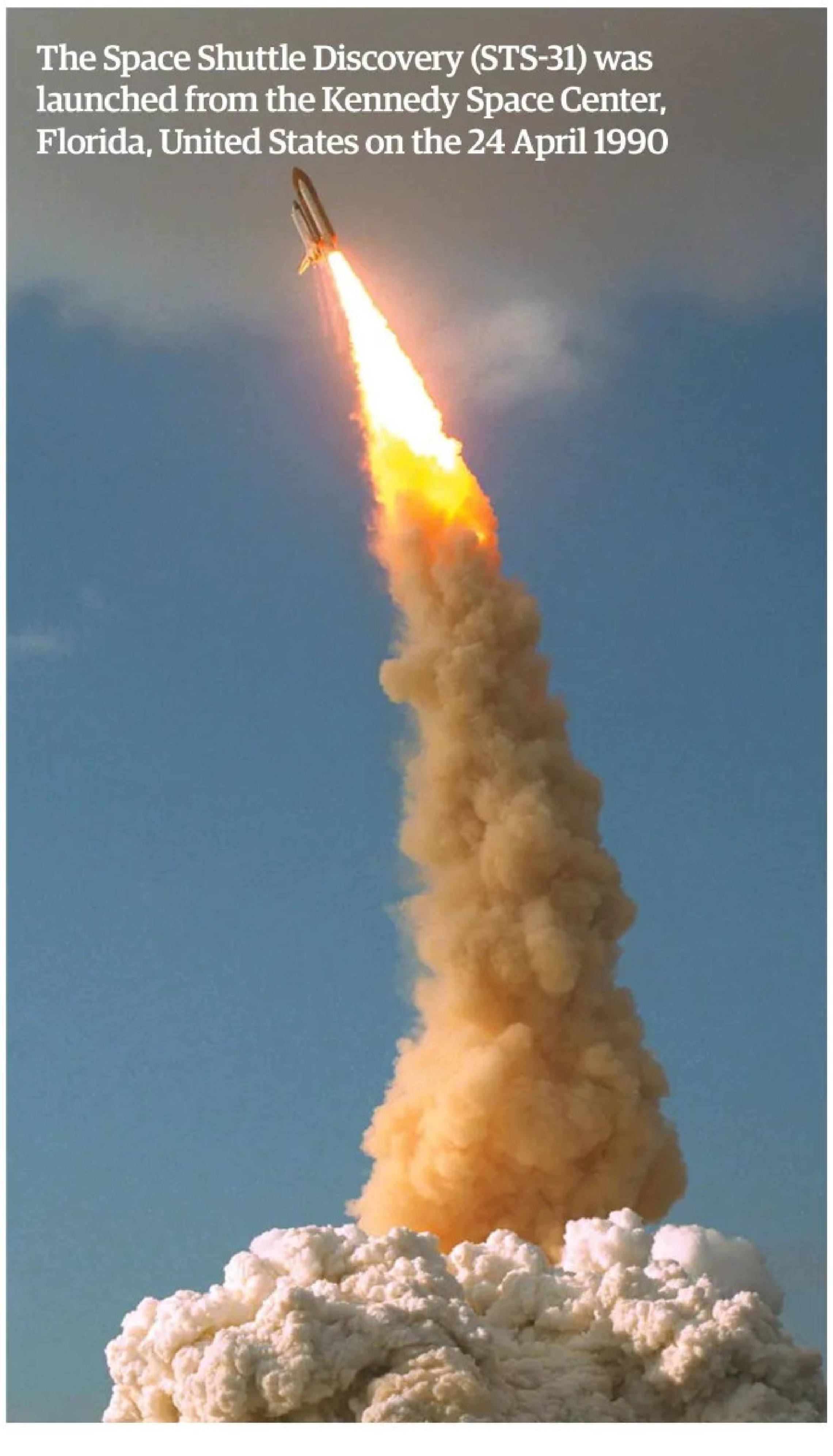
The longevity of Hubble has been a pleasant surprise, with many scientists thinking Hubble would be long gone before the launch of its successor, NASA's James Webb Space Telescope (JWST), due to be launched towards the end of 2021. Now it looks more likely that the space telescopes' lifetimes will overlap, giving scientists and researchers a few years to utilise having two of the greatest telescopes in space at the same time to gather precious information about the universe. There is something Hubble can do that the JWST will not have the capabilities for though, and that's observing ultraviolet light. JWST will be able to observe visible to mid-infrared light in unprecedented detail, but not ultraviolet. This is why the Hubble scientists are urging researchers to gather as much ultraviolet information as they can with Hubble before it's too late. Once Hubble is decommissioned, these precise measurements of celestial objects in a wavelength unperceived by the human eye will no longer be available.

"We're encouraging them [researchers around the world] to consider making ultraviolet light observation proposals in order to give us information and data for future use. This will be more scientifically valuable because the Hubble Space Telescope can see in ultraviolet light, but there's no space telescope [planned to launch] in the near future that will be able to make these observations, and we cannot receive ultraviolet light from the ground because the atmosphere blocks it," Dr Jennifer Wiseman, senior project scientist for the Hubble Space Telescope, explains. "Hubble is unique in this capability of doing ultraviolet light observations and it is very informative for all kinds of astronomy. We use it both for studying the Solar System as well as studying the intergalactic medium – the material that connects galaxies. Those are just two examples of features in space that ultraviolet observations can truly illuminate and help us understand."

Ultraviolet can tell us a lot of hidden information about the universe, particularly about the birth of hot, young stars. The intergalactic medium contains copious amounts of gas and dust, material fundamental for bringing life to stars. Ultraviolet spectroscopy – the splitting apart of light to observe chemical signatures – can tell us what elements are

**Hubble's final servicing mission occurred between 11-24 May 2009**

**Dr Jennifer Wiseman is the senior project scientist for the Hubble Space Telescope**



**The Space Shuttle Discovery (STS-31) was launched from the Kennedy Space Center, Florida, United States on the 24 April 1990**

> "Hubble is unique in this capability of doing ultraviolet light observations. It is very informative" **Dr Jennifer Wiseman**

in these gas clouds, what temperature it is and even their density. From this, we can deduce what the ideal conditions are for stars to be born. So, as making use of a telescope living on borrowed time is of the highest priority, Hubble scientists have introduced a 'mid-cycle proposal initiative'. "This is a special additional opportunity that astronomers have at two other times in the year, so we call them 'mid-cycle proposals', with a cycle being a year basically," says Wiseman. "These extra opportunities allow astronomers to make the case that if they go ahead and make a short observation with Hubble that's a time-sensitive issue, it will help them to have a richer proposal when the regular annual cycle proposal comes around."

By allowing astronomers to fast track the usual annual proposal process, assuming that their mid-cycle proposal fits the urgent protocol, the efficiency for the 30-year-old space telescope can be optimised while it is still in fantastic condition. Even if this work never goes further than that, the observations will always remain in the fine collection of datasets that is the Hubble archives. Already the Hubble archive is making tremendous contributions to science with new discoveries; about half of the published scientific papers based on Hubble data have come from this trove of forgotten gems. Every so often a story emerges of another discovery in the data.

"There is another area we are using Hubble in which I think is of prime importance, and that is studying our Solar System," explains Wiseman. Although Hubble spends a lot of time staring into deep space, pondering upon the darkest, deepest galaxies in the universe, it can also tell us much about the outer planets in our Solar System. The only instruments that can produce clearer pictures are the ones that have flown past the planets, such as Juno, Cassini, the Voyager spacecrafts and so on. The advantage that Hubble has over these exploration spacecrafts, however, is that Hubble can observe these planets periodically for many years.

With this perpetual 'checking in' on our outer planets, Hubble managed to capture the spectacular collision between comet Shoemaker-Levy 9 and Jupiter in July 1994. Hubble has also deduced that the aforementioned planet's Great Red Spot (GRS), a storm about 1.3-times the diameter of Earth, is shrinking. Even today scientists continue to make new discoveries thanks to these periodic observations. For instance, scientists recently caught a storm – originally long enough to stretch from the East Coast of the United States to Portugal – on the face of Neptune, shrinking before its very lens.

As for the future, scientists are extremely keen to keep a close eye on Jupiter's moon, Europa. Europa has exhibited plumes of water escaping from within the moon, meaning that there could be a subsurface ocean. With Hubble's ultraviolet capabilities a lot can be learned from the water beneath the ice; it could even point out the existence of microbial life.

Even beyond our Solar System we are still learning about planets in our galaxy, the Milky Way. More specifically the atmospheres of exoplanets – planets orbiting a star other than our Sun. "Hubble is very useful for studying the atmospheric compositions of some of these exoplanets, so we're using Hubble very intensively to do that on as many exoplanets as we can," explains Wiseman. "We've already found water vapour in the atmospheres of several exoplanets, and we're continuing to characterise as many as we can in several wavelengths of light."

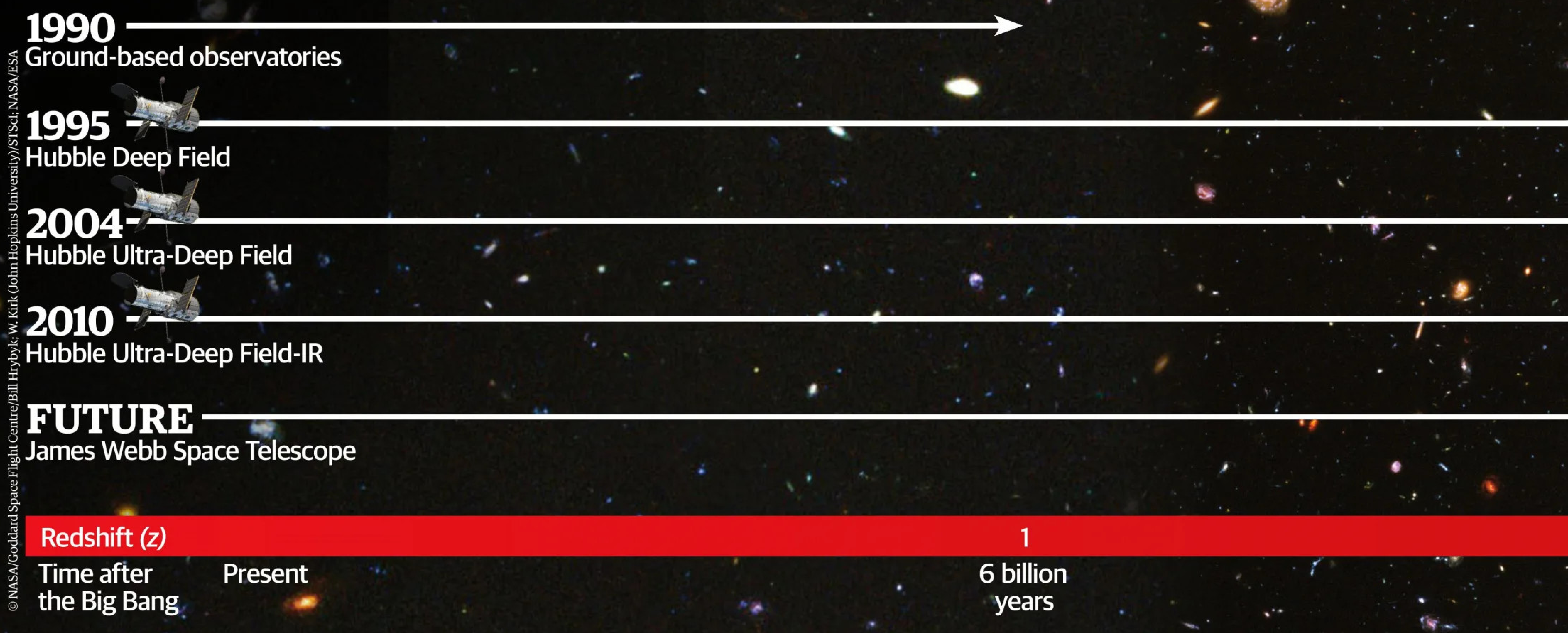
Moving beyond the Milky Way, the Hubble Space Telescope has played a vital role in understanding the expansion of the universe or, more appropriately, causing even more confusion surrounding the expansion of the universe. Dr Adam Riess, 2011 Nobel Prize laureate and astrophysicist at the Space Telescope Science Institute and Johns Hopkins University, both in Baltimore, Maryland, United States, formulated an innovative technique that led to a more accurate figure for the Hubble constant and a better understanding of it.

The Hubble constant is the rate at which the universe is expanding, and after eight long years of observing Cepheid stars, Riess and his team were able to conclude that the universe is expanding five to nine per cent faster than expected. When the refined Hubble data is compared with information we can see from the cosmic microwave background (ancient

**Patrick Crouse has been Hubble's project manager for ten years**

## How Hubble will benefit the James Webb Space Telescope

When NASA's James Webb Space Telescope receives first light it will be ready to peer earlier into the universe's history than ever before. Until then, Hubble can identify and analyse the earliest galaxies its optics allow, singling out targets for the JWST to look at once its time has come.



© NASA/Goddard Space Flight Centre/Bill Hrybyk; W. Kirk (John Hopkins University)/STScI; NASA/ESA

Adam Riess won the Nobel Prize in Physics in 2011 for his research on the expansion of the universe

radiation left from the Big Bang), astronomers can't get the two results to match up, which means there could be something wrong with our understanding. Riess says that this can be thought of as building a bridge, with the Hubble findings on one side and the cosmic microwave background data on the other. "You start at two ends, and you expect to meet in the middle if all of your drawings are right and your measurements are right. But now the ends are not quite meeting in the middle, and we want to know why," he explains.

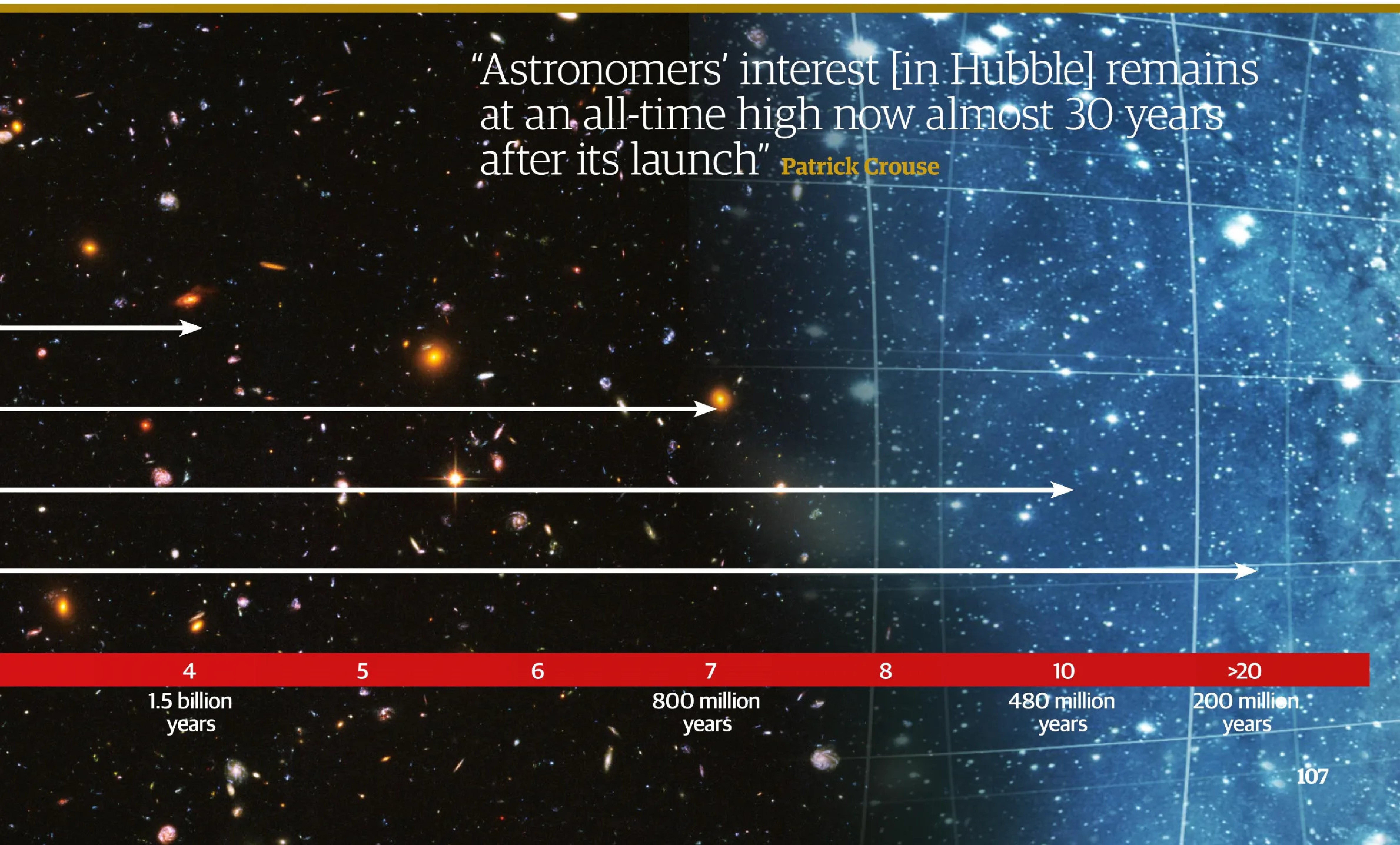
This incentive continues to drive astronomers in their quest to understand the elusive dark energy theorised to be fuelling the expansion of our universe. Since 2005, the uncertainty for the Hubble constant value has been reduced to just 2.4 per cent, which is a 76 per cent reduction. However, Riess and his team strive to make this uncertainty just one per cent, and hopefully connect the bridge between the two sets of data.

In spite of all that, it has become abundantly clear that the hard-working Hubble team at NASA are planning heavily for the arrival of the agency's highly anticipated James Webb Space Telescope. Prior to its arrival, Hubble will spend a fair amount of its time in the coming years undergoing preparatory observations and getting all the aims, objectives and targets ready for when the new space telescope receives first light.

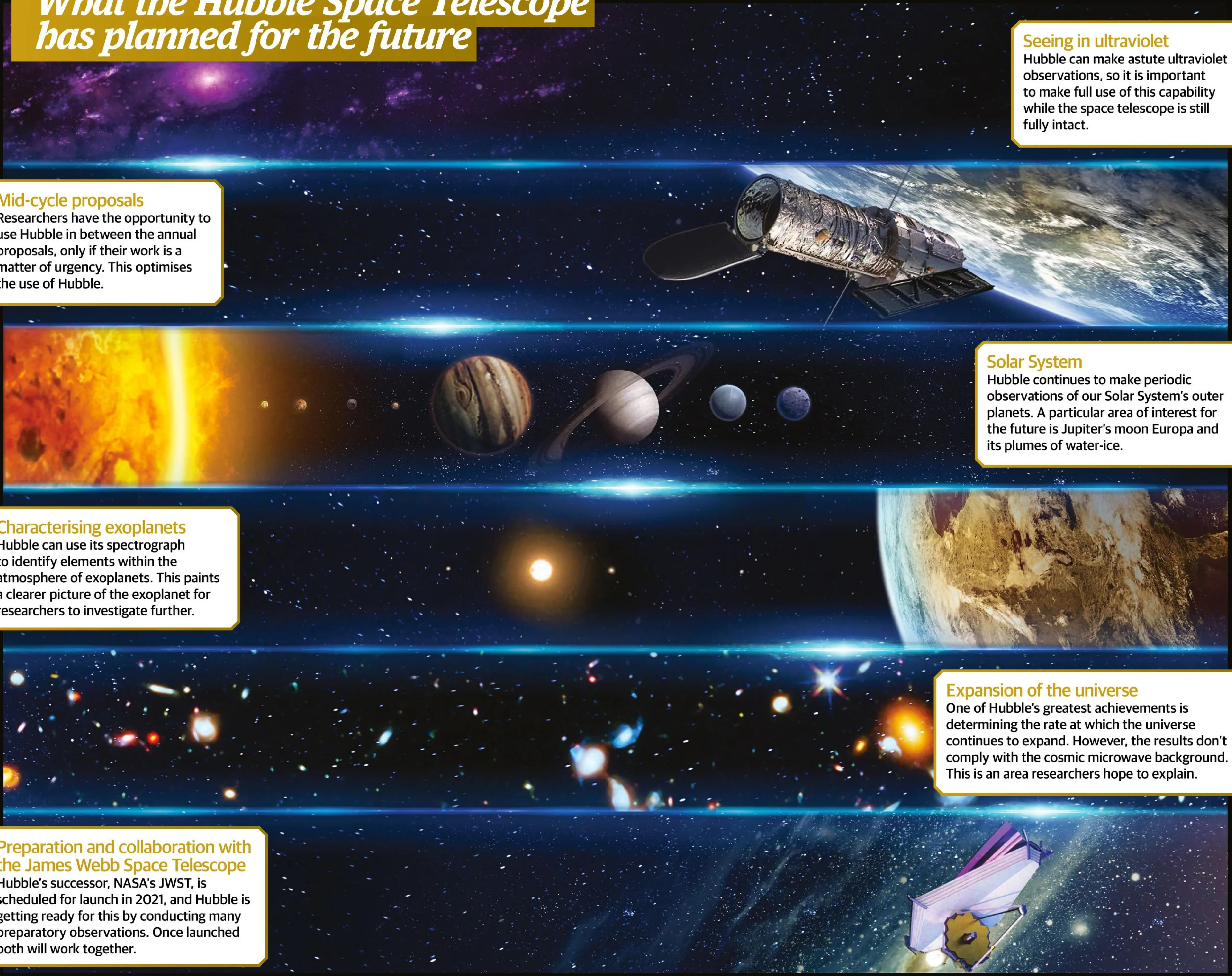
"We look forward to overlapping operations with the JWST telescope and the resulting

On Hubble's 25th anniversary, it celebrated by snapping this marvellous shot of the star cluster Westerlund 2

> "Astronomers' interest [in Hubble] remains at an all-time high now almost 30 years after its launch" **Patrick Crouse**



# What the Hubble Space Telescope has planned for the future



## Seeing in ultraviolet

Hubble can make astute ultraviolet observations, so it is important to make full use of this capability while the space telescope is still fully intact.

## Mid-cycle proposals

Researchers have the opportunity to use Hubble in between the annual proposals, only if their work is a matter of urgency. This optimises the use of Hubble.

## Solar System

Hubble continues to make periodic observations of our Solar System's outer planets. A particular area of interest for the future is Jupiter's moon Europa and its plumes of water-ice.

## Characterising exoplanets

Hubble can use its spectrograph to identify elements within the atmosphere of exoplanets. This paints a clearer picture of the exoplanet for researchers to investigate further.

## Expansion of the universe

One of Hubble's greatest achievements is determining the rate at which the universe continues to expand. However, the results don't comply with the cosmic microwave background. This is an area researchers hope to explain.

## Preparation and collaboration with the James Webb Space Telescope

Hubble's successor, NASA's JWST, is scheduled for launch in 2021, and Hubble is getting ready for this by conducting many preparatory observations. Once launched both will work together.

© NASA; Nichoals Forder

Five servicing missions took place for Hubble over the space of 16 years

“We look forward to similar, joint programmes with JWST so that investigators can coordinate the study of celestial objects in detail” **Kevin Hartnett**

complementary science opportunities, which we expect to be very exciting,” says Crouse.

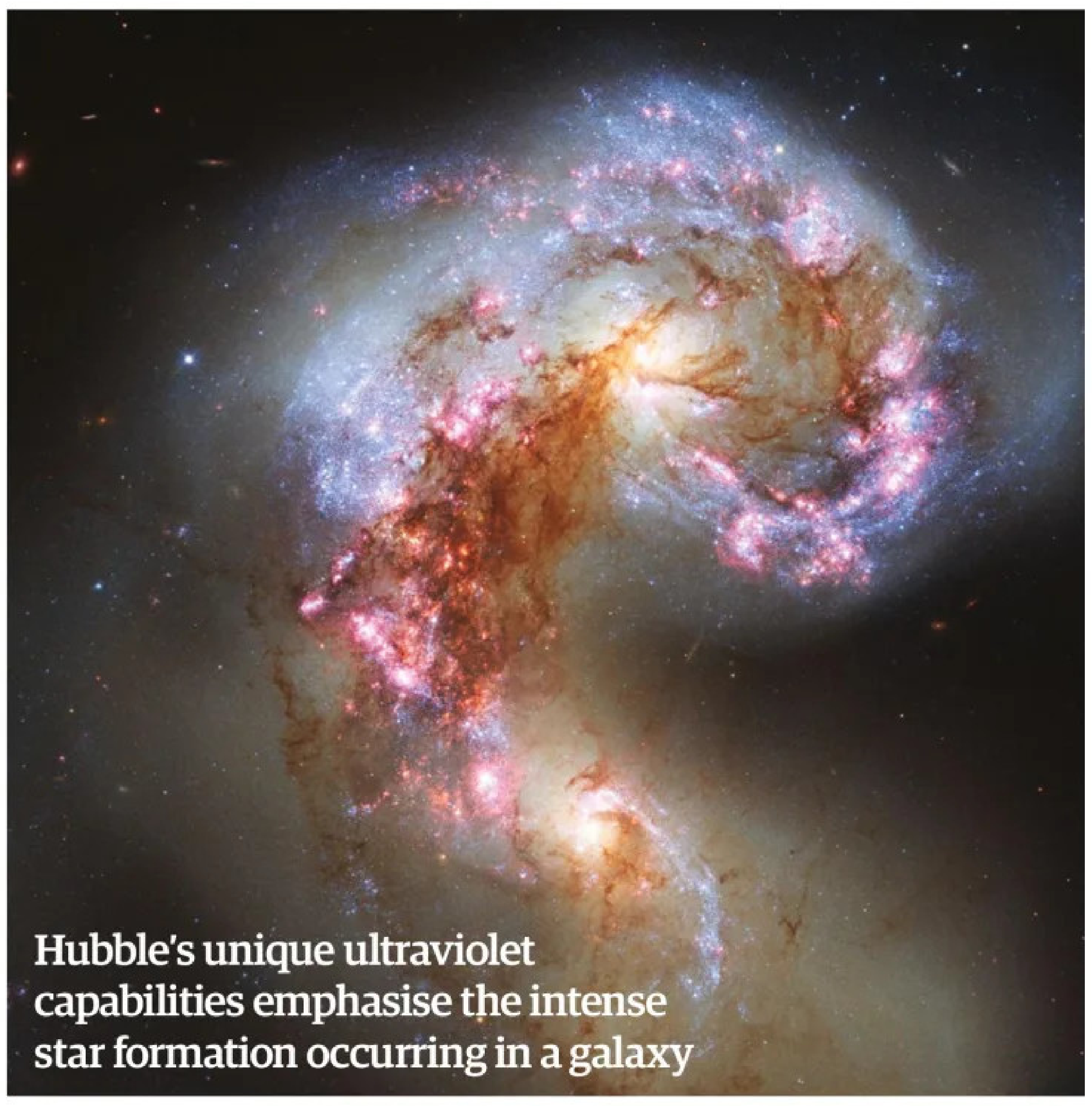
Kevin Hartnett, science operations manager of the Hubble Space Telescope explains “Once James Webb Space Telescope is launched and is taking science we look forward to similar, joint programmes with JWST so that investigators can coordinate the study of celestial objects in detail panchromatically, that is, across the electromagnetic spectrum, from ultraviolet to infrared wavelengths.”

The JWST will be able to do the same things as the Hubble Space Telescope – minus ultraviolet observations – but better. With its 18 hexagonal mirrors, each beryllium blank is coated in gold, congregating into a 6.5-metre (21-foot) primary mirror, it will tower over Hubble's 2.4-metre (7.9-foot) mirror, allowing for marvellous light-capturing capabilities. With this incredibly powerful instrument at NASA's disposal, astronomers are now planning what the first targets will be in order to kick-start a new era of deep-space exploration.

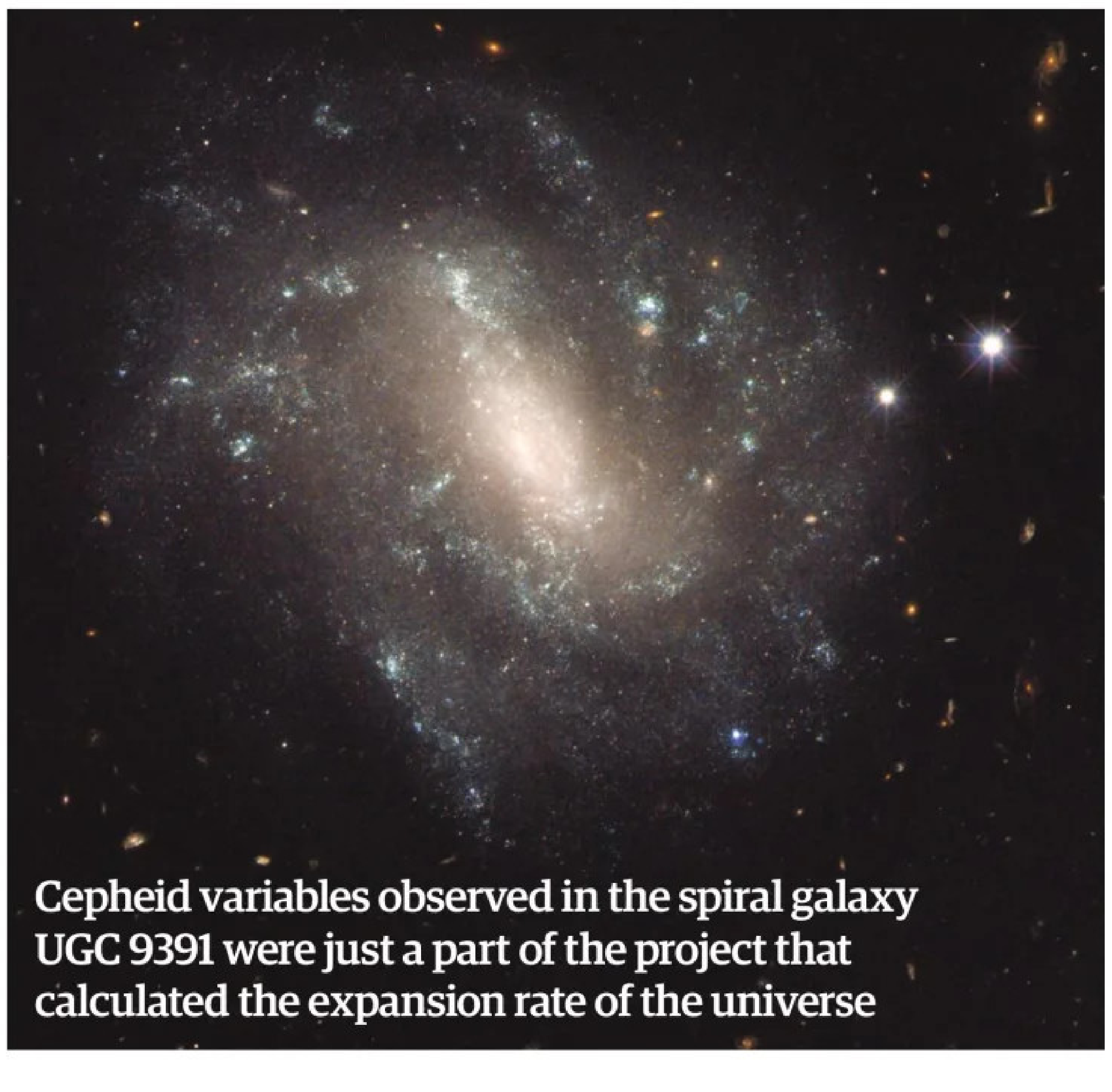
One area that astronomers around the world are at the edge of their seats for, in terms of JWST's preliminary results, are observations with respect to the most distant galaxies in the universe. The most distant galaxies are normally referred to as high-redshift galaxies. This is because the more distant the light source is, the more stretched the light's wavelength is towards the red part of the spectrum. But what can these distant galaxies tell us about our universe? The answer is that they can tell us about the early ages of the universe, due to the limited speed of light and the large distance travelled since the birth of these galaxies.

In March 2016, Hubble imaged the most distant galaxy in the universe. It was dubbed GN-z11, based on the fact it has a redshift value (*z*) of 11. As light is limited to the speed of 300,000,000 metres per second (671,000,000 miles per hour), the light from GN-z11 had taken over 13 billion years to reach us. Hubble had just spotted a galaxy that formed just 400 million years after the Big Bang! With the greater light-gathering capabilities of JWST, we could potentially unlock a whole new horde of remote, young galaxies. This information can then tell us what the universe was like just a few hundreds of millions of years after the Big Bang.

Even after over 30 years of around-the-clock operation, Hubble remains the most successful and scientifically significant telescope ever created. It is remarkable what it has done, what it is currently doing and what it will do in the future. However, with its longevity in question and the eventual arrival of the JWST, it's clearly important to utilise these precious final years. After all, Hubble has built, and will continue to build, an amazing collection of data for scientists all over the world to prosper from long after the telescope itself has gone.



Hubble's unique ultraviolet capabilities emphasise the intense star formation occurring in a galaxy



Cepheid variables observed in the spiral galaxy UGC 9391 were just a part of the project that calculated the expansion rate of the universe

©ESA/NASA/Hubble

# OPPORTUNITY'S 15 YEARS ON MARS

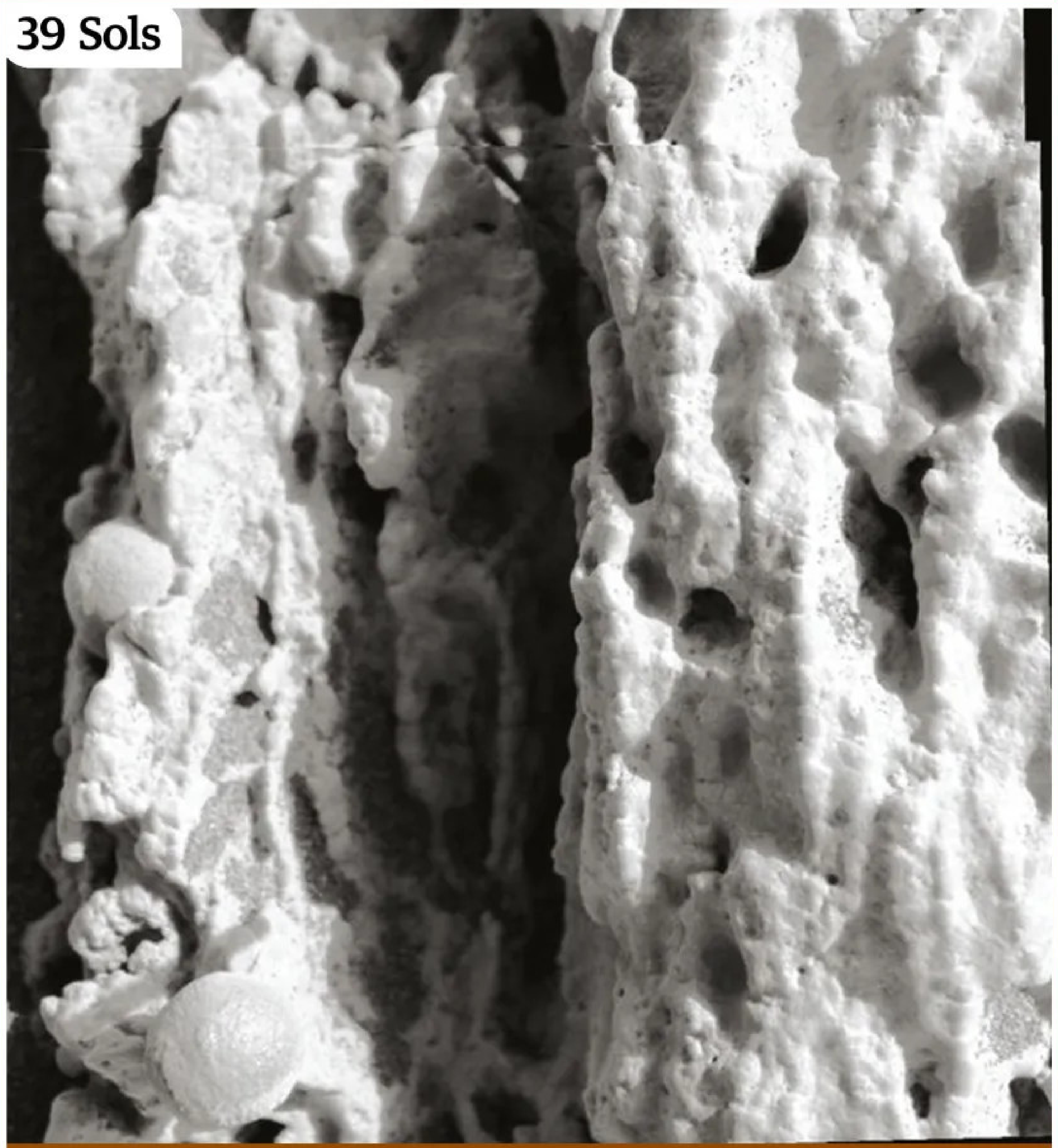
Designed to last 90 days, Opportunity survived for over a decade on Mars. Here we look back on how the record-breaking rover changed the way we see the Red Planet

1 Martian solar day (Sol) = 1.027 Earth days

## Opportunity's objectives

- Search for signs of past liquid water ✓
- Determine distribution and composition of Martian rocks ✓
- Discover the geological processes which formed the Martian terrain ✓
- Validate measurements made by probes orbiting Mars ✓
- Search for iron containing minerals that may have been formed in water ✓
- Determine the texture of rocks and soils and what created them ✓
- Assess whether Mars' climate was ever fit for life ✓

**39 Sols**



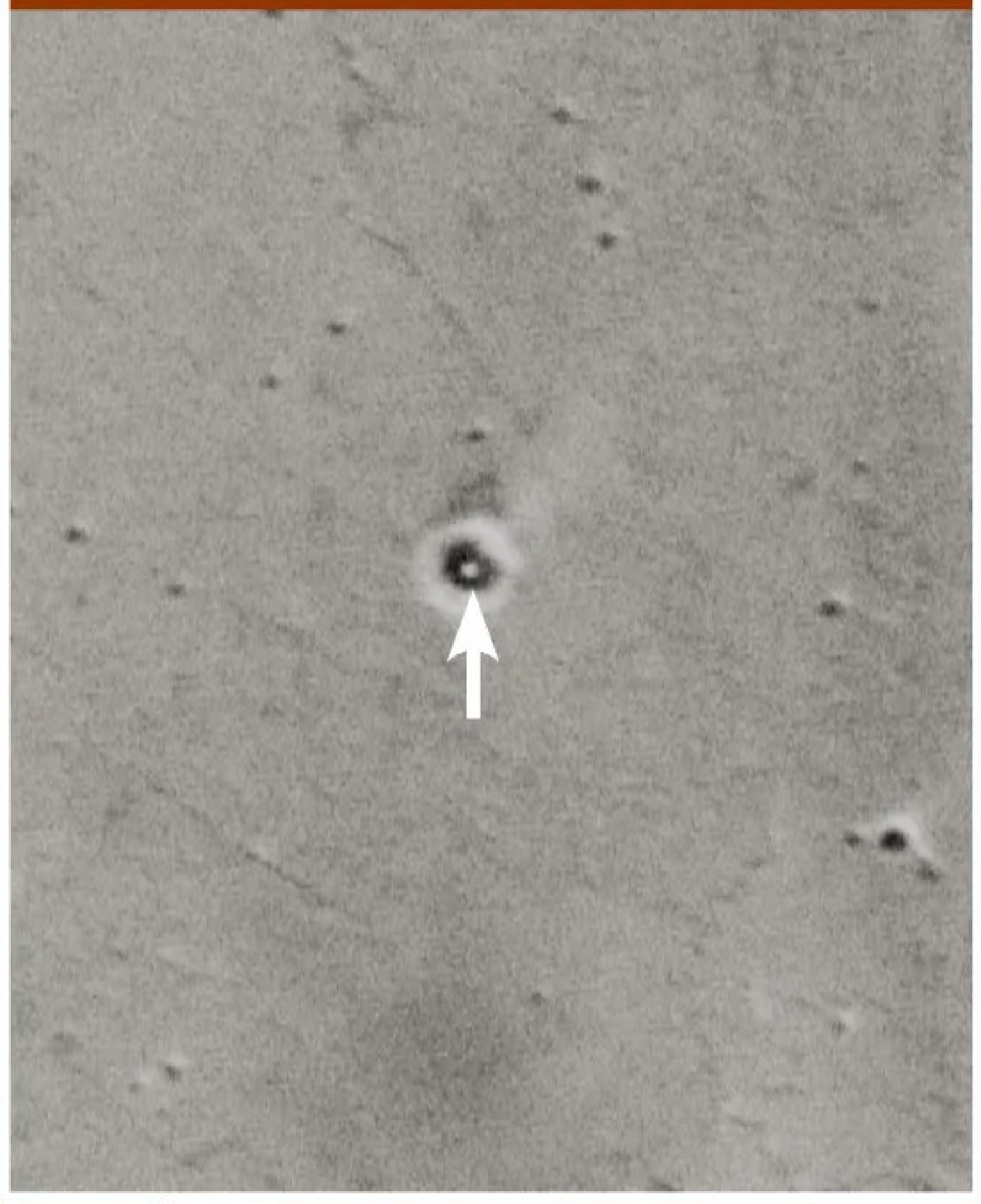
### Signs of past water

This is a microscopic image of part of a rock called 'Last Chance'. The view here is around five centimetres (two inches) across and was taken on Opportunity's 39th Martian day. The texture of the rock has led scientists to believe that water was once present in the area in which it was found – the Meridiani Planum area of Mars, which is close to its equator.

**91 Sols**

### Opportunity from orbit

Opportunity's journey across Mars has been closely watched and calibrated by the satellites in orbit around the Red Planet. This image from NASA's Mars Global Surveyor shows some of the tracks of the rover, the craters it was visiting, its back shell and parachute, along with the location of its discarded heat shield. It was taken on 26 April 2004 on Sol 91 from a distance of around 400 kilometres (249 miles).

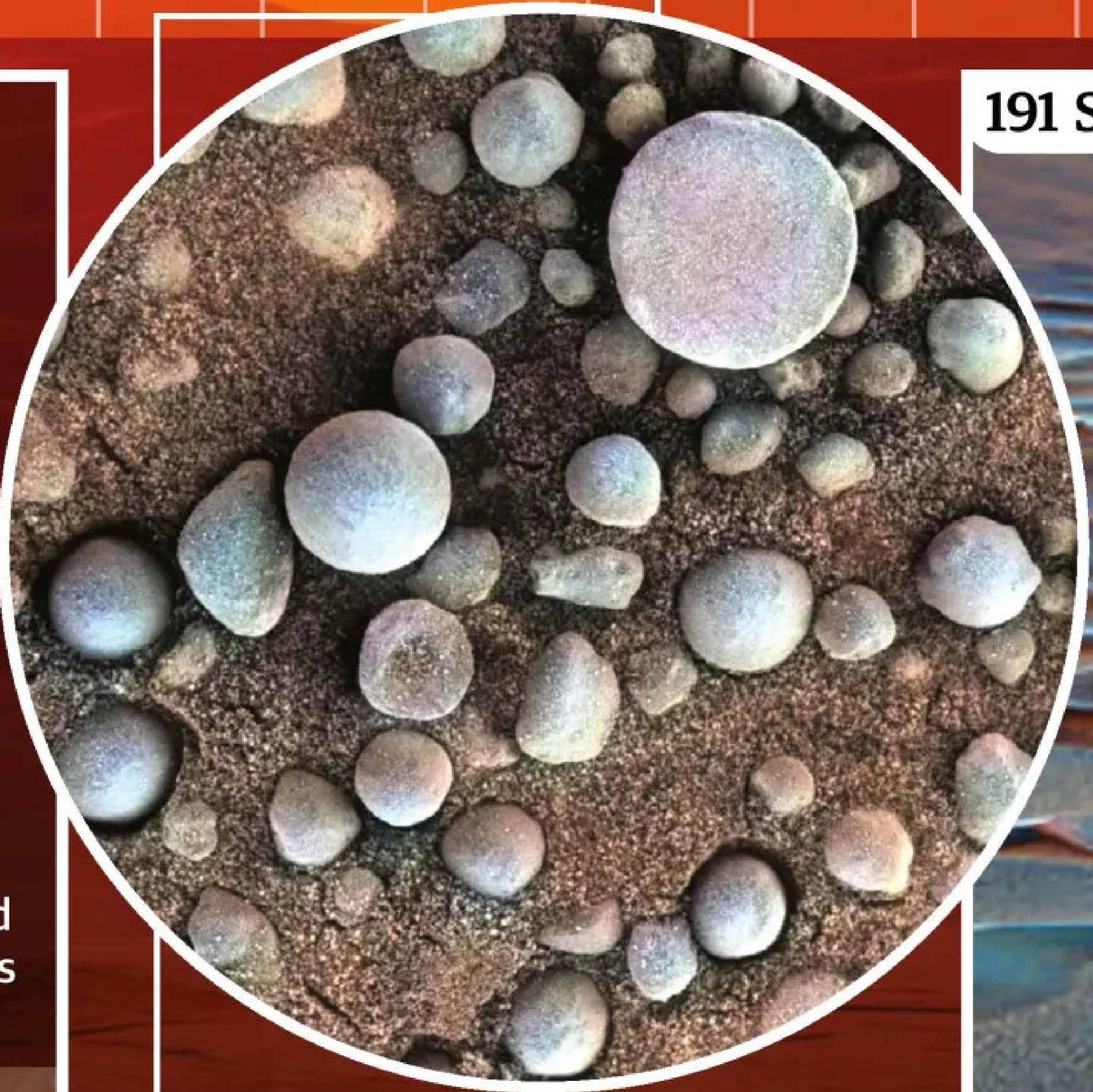


0
50
100
150
200

**0 Sols**

### Made of World Trade Center metal

Part of Opportunity is made from aluminium debris salvaged from the World Trade Center, which collapsed on 11 September 2001. It was turned into a credit-card-sized sheet of metal, to which a United States flag emblem was added. That metal protects the cables that form part of Opportunity's drilling mechanism. The same is true of the Spirit rover. The team who built the part worked just six blocks away from the towers in downtown Manhattan.

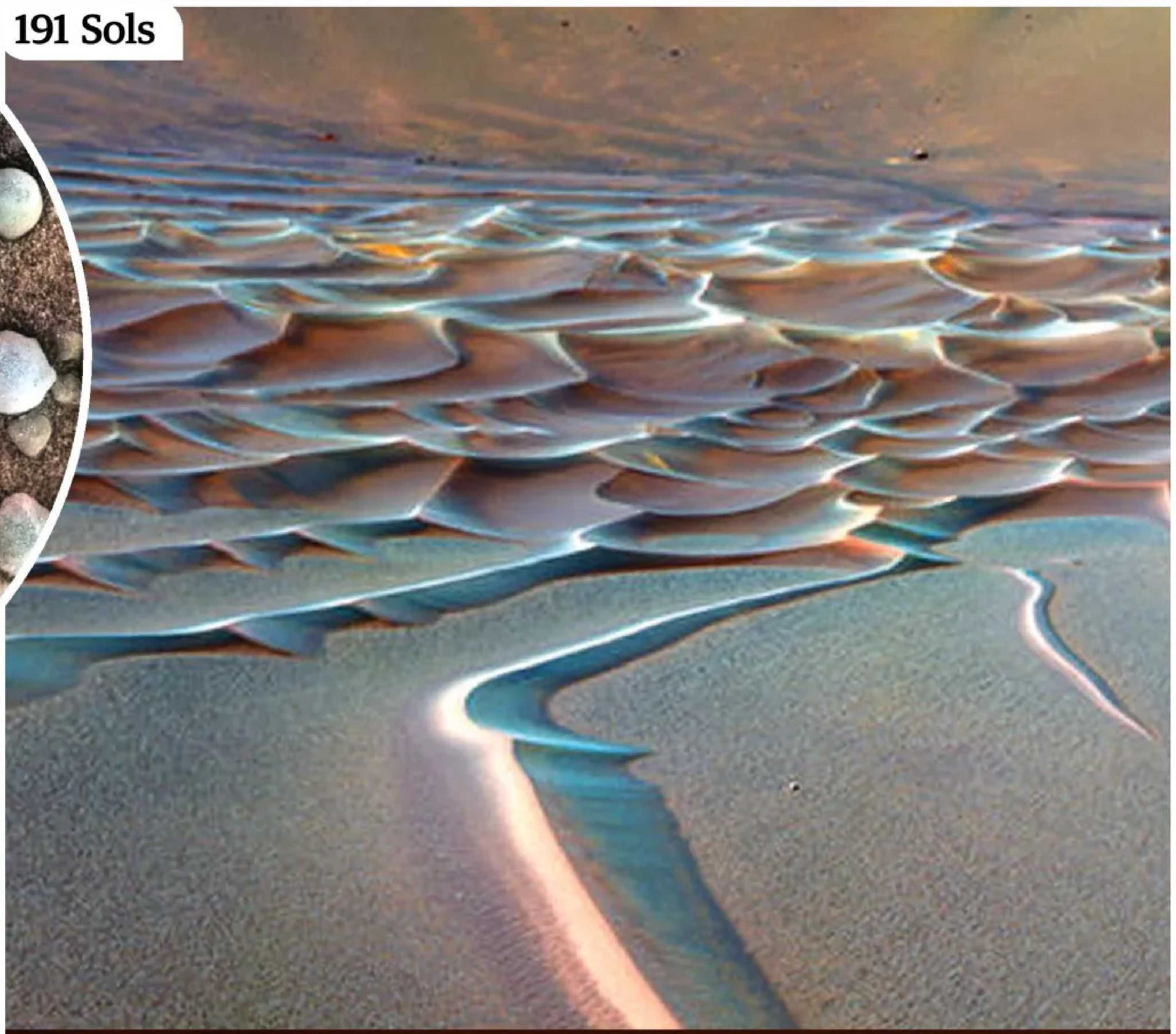


**84 Sols**

### Martian blueberries

Microscopic analysis of the Martian surface revealed tiny spheres resembling blueberries. Each of the balls you can see here is a few millimetres across. This image was taken near Fram crater in April 2004 on Opportunity's 84th Sol on Mars and shows how the mineral hematite can come together to form small structures. It has been suggested they were deposited here by liquid water long ago in Mars' warmer past.

**191 Sols**



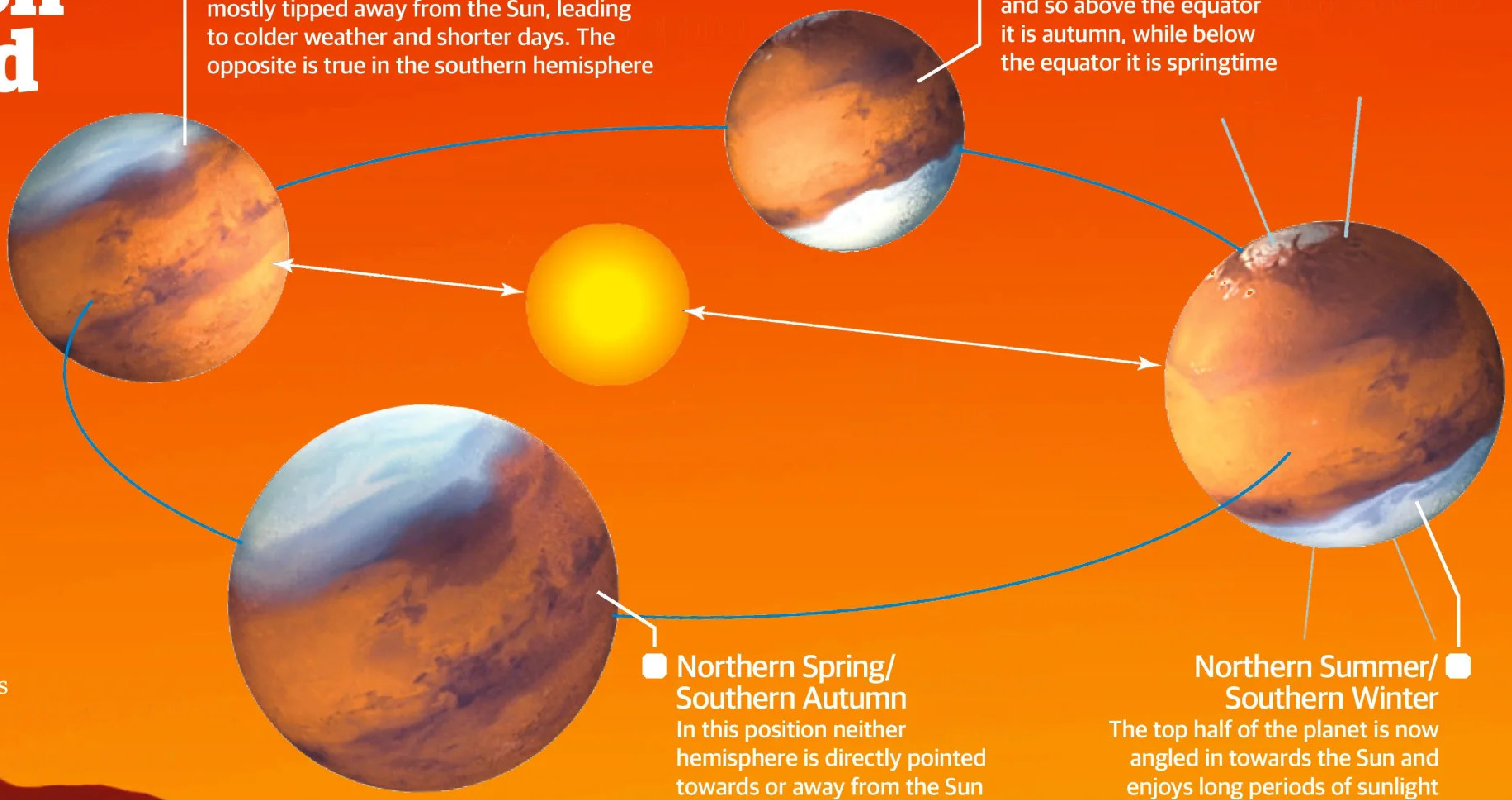
### Sand dunes

As Opportunity entered Endurance crater it found dunes on the crater floor. Each of the ridges of sand are less than one metre (3.3 foot) high and are likely caused by the winds that whip across the dry Martian surface. Before approaching the dunes to take the photograph, the rover drivers had to assess the likelihood of Opportunity becoming marooned in the dunes. The image is in false colour and was taken by the PanCam instruments on board the rover.

257 Sols

# Frost on the Red Planet

Being further from the Sun than the Earth, temperatures on Mars regularly plummet below freezing. On October 13 2004, 11 minutes after sunrise, NASA scientists noticed that frost had formed on one of the calibration targets for the PanCams. So even near the equator - the location of Opportunity's landing site - temperatures drop enough for frost to form. No such frost observations were seen on Spirit, Opportunity's twin rover, which was situated on a different part of the planet.

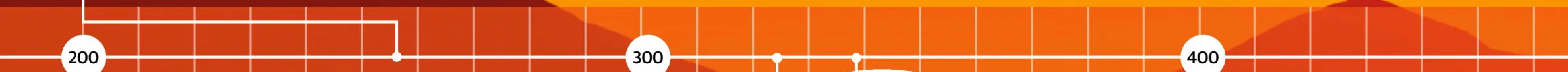


**Northern Winter/Southern Summer**
Here the planet's northern hemisphere is mostly tipped away from the Sun, leading to colder weather and shorter days. The opposite is true in the southern hemisphere

**Northern Autumn/ Southern Spring**
Once again, neither pole is angled towards the Sun and so above the equator it is autumn, while below the equator it is springtime

**Northern Spring/ Southern Autumn**
In this position neither hemisphere is directly pointed towards or away from the Sun and so the two hemispheres enjoy spring and autumn respectively

**Northern Summer/ Southern Winter**
The top half of the planet is now angled in towards the Sun and enjoys long periods of sunlight and warmer weather, while it is largely cold and dark in the south



324 Sols

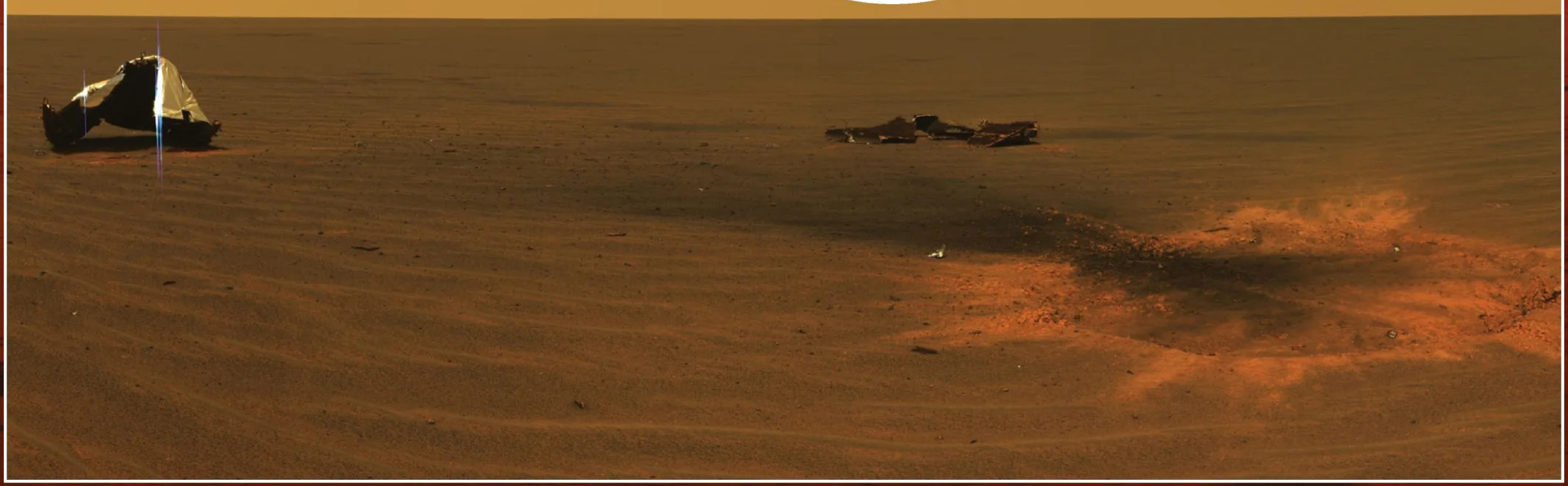
## Glancing at its impact site

In this image you can see the area where the rover's heat shield impacted the Martian surface. It was taken on Sol 324, so nearly a year after Opportunity touched down on Mars. The main heat shield is on the left-hand side and is sitting inverted. The circular crater created by the heat shield is 2.8 metres (9.2 foot) wide, but no more than ten centimetres (four inches) deep.

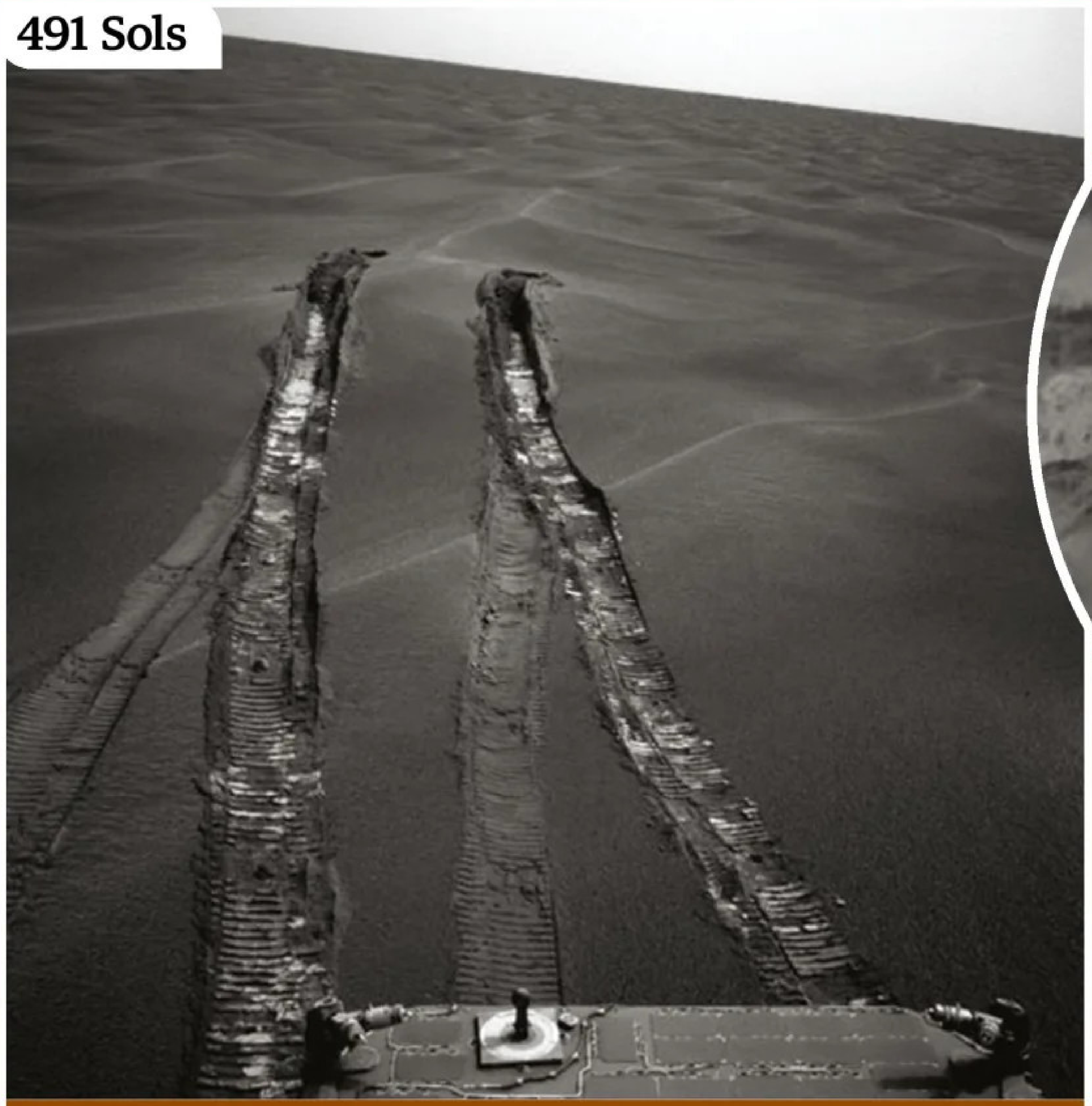
339 Sols

## Meteorite find

In January 2005, Opportunity was examining the impact site of its own heat shield when it came across a meteorite on the surface of Mars. It was subsequently named Heat Shield Rock. About the size of a basketball, it was the first meteorite to be discovered on another planet (two others had previously been found on the Moon). Its iron structure meant that the abrasion tool could not be used to scratch it, as it would have been damaged.

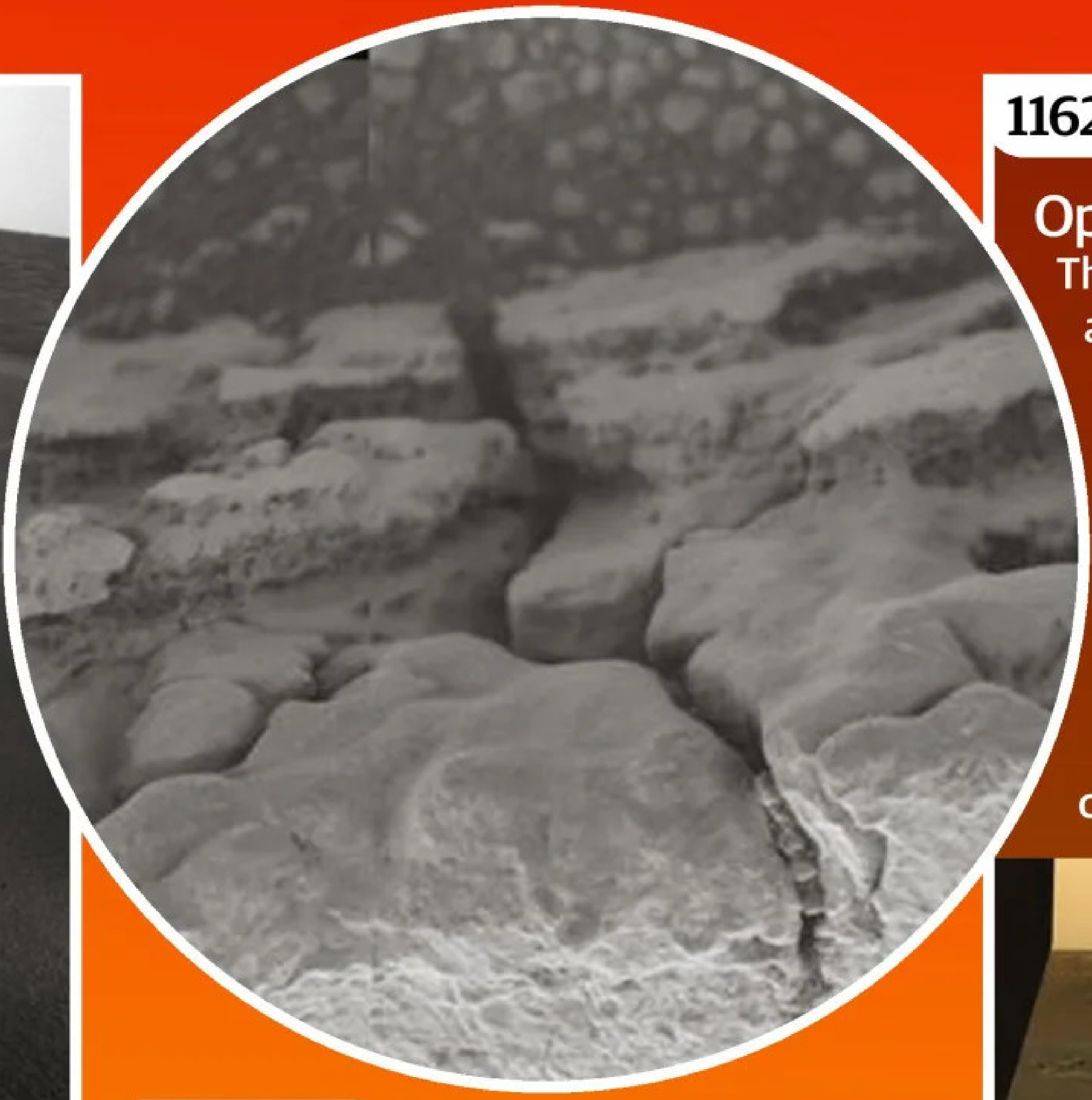


**491 Sols**



### Stuck in Purgatory

During April 2005, Opportunity's wheels became embedded more than ten centimetres (four inches) down into some soft, sandy material. It took five weeks of planning, testing and expert driving in order to extricate the stricken rover. Due to its hellish effect on Opportunity, this region was dubbed Purgatory Dune. It could nearly have been the rover's final resting place. Luckily, it was able to escape and has continued to operate for more than a decade after its little mishap.



**727 Sols**

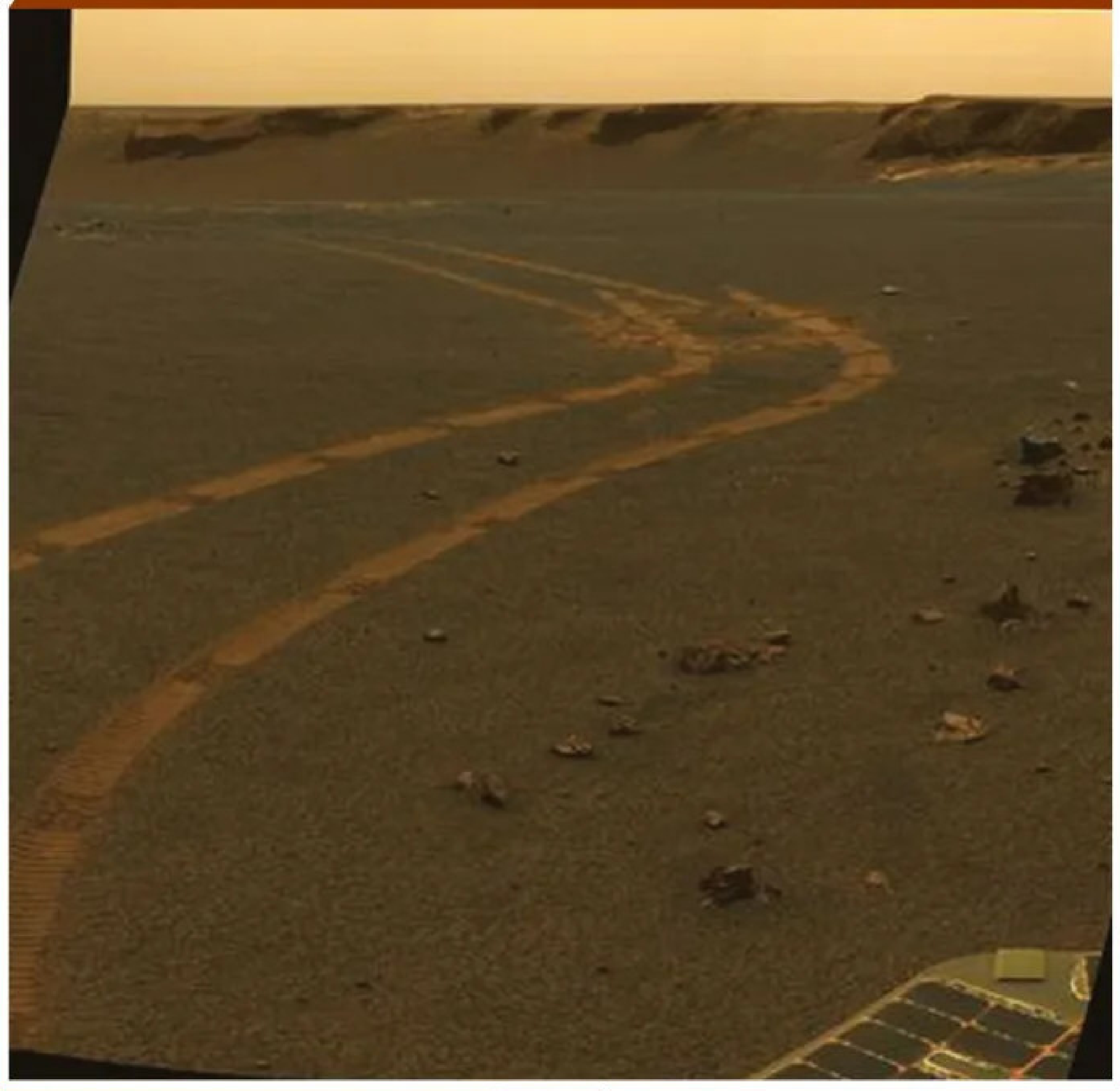
### Signs of water at Roosevelt

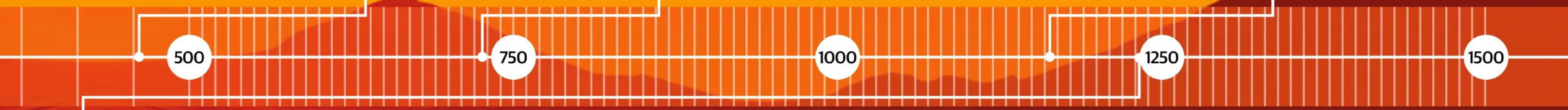
Opportunity's microscope shows a close-up view of a structure known as Roosevelt, found near the edge of Erebus crater. Scientists have hypothesised that the fractures were caused by liquid water moving through the structure. The image is a mosaic of several smaller images all taken on Sol 727. The feature is younger than the surrounding rocks, meaning that liquid water may have been present in the area after the other sedimentary rocks had formed.

**1162 Sols**

### Opportunity learns to drive itself

This view of Opportunity's tyre tracks was taken after it drove a curved path that was more self-determined than before. Engineers were testing out a piece of software called Field D-star, which helps Opportunity decide for itself how to get to a given destination while avoiding obstacles along the way. It was taken on Sol 1162 and Victoria crater can be seen in the background. For scale, the rocks in the centre foreground are seven to ten centimetres (2.8 to 3.9 inches) tall.

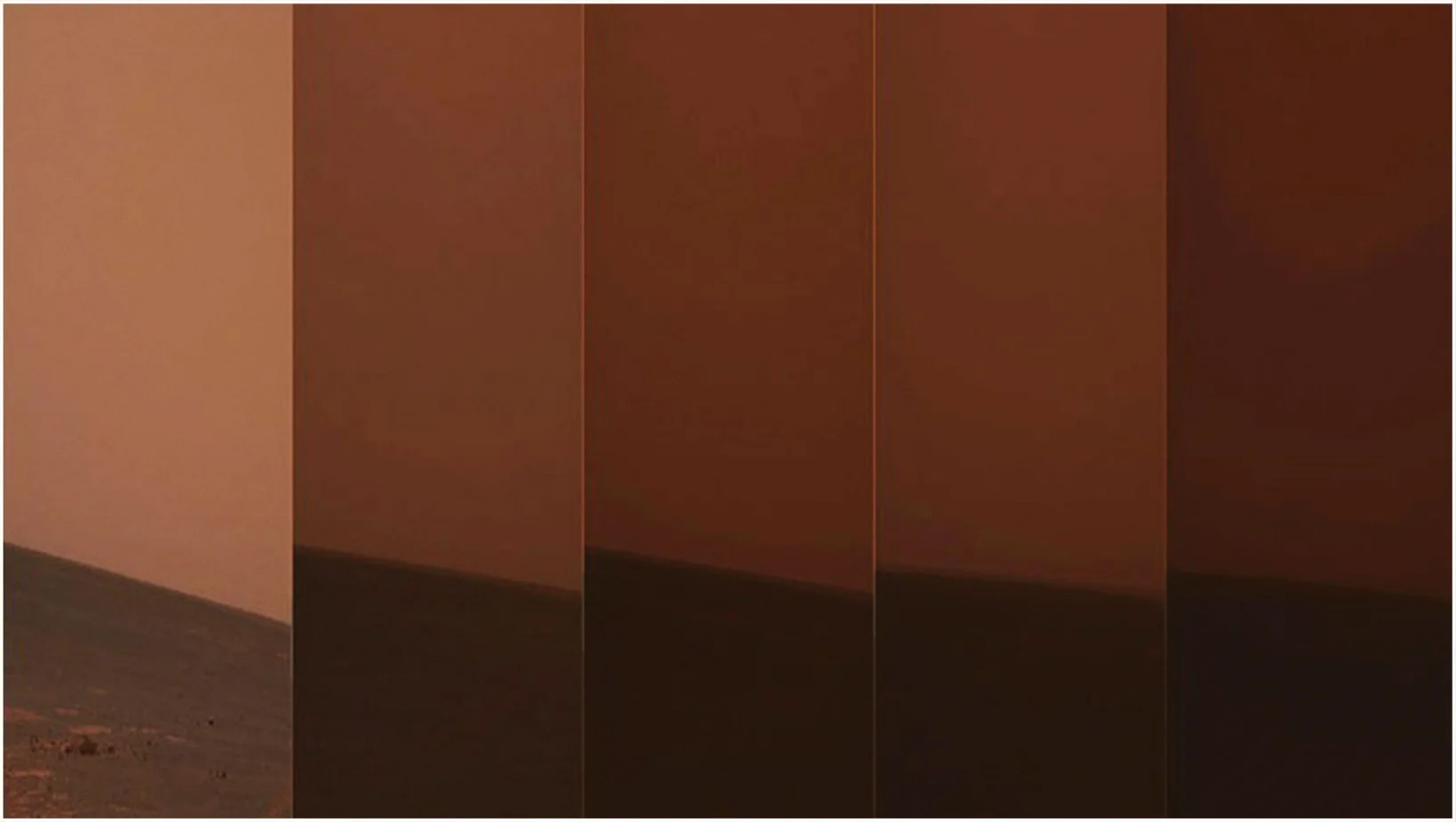




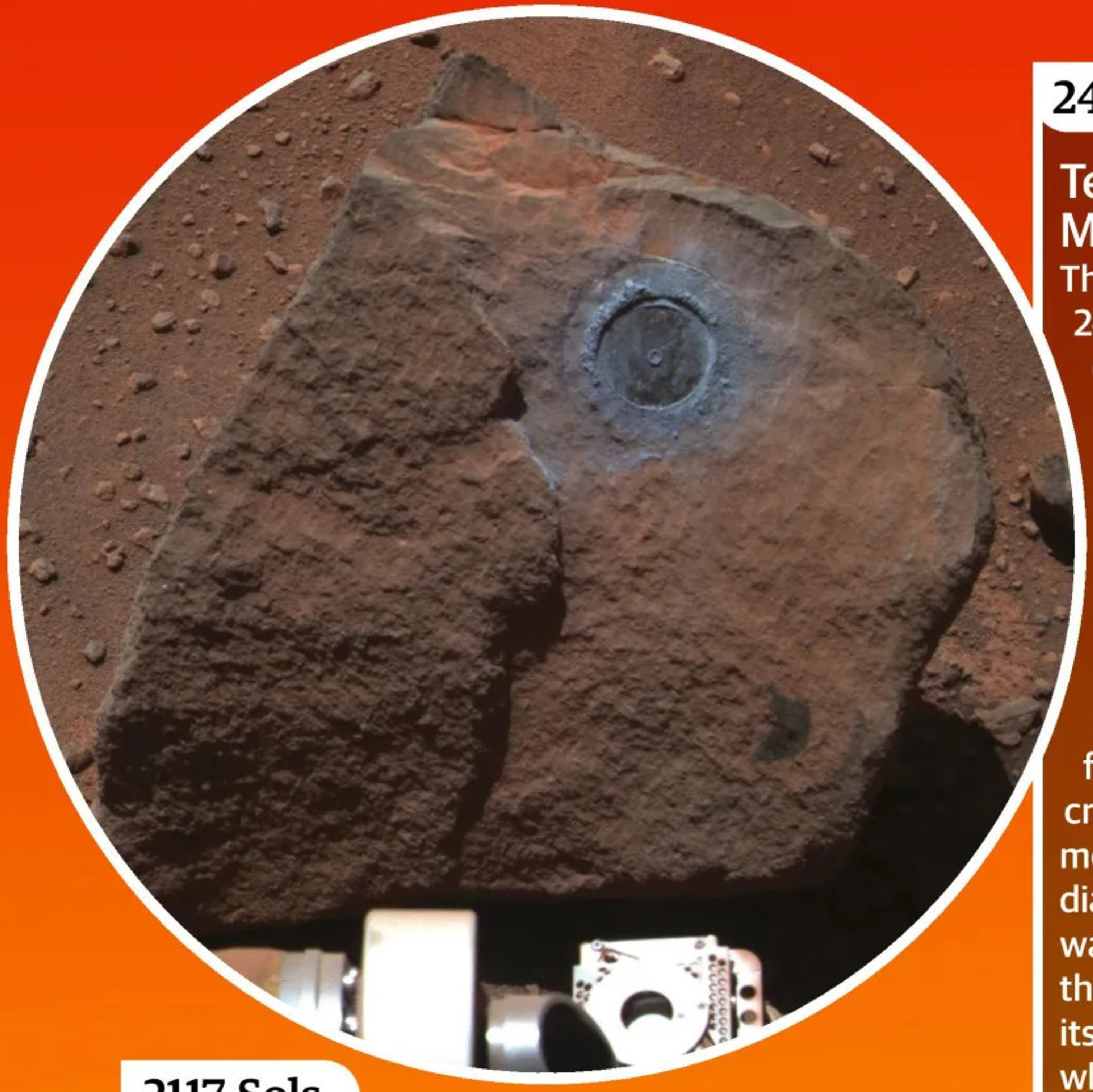
**1236 Sols**

# Opportunity encounters its first dust storm

In July 2007 both Opportunity and its twin rover Spirit came under severe threat from vicious dust storms whipping across the Martian surface. The rover gets its power from its array of solar panels, but the huge volume of dust brought by the storms blocked out 99 per cent of the available sunlight. Opportunity was effectively put into hibernation for a few days and the amount of contact with the rover was scaled back. Fortunately, the storms moved away and the rover survived intact.



As the dust storm gathered, the amount of daylight available to the Opportunity rover dropped dramatically. These images, taken by the rover's PanCam, shows how the sky darkened over several weeks



**2117 Sols**

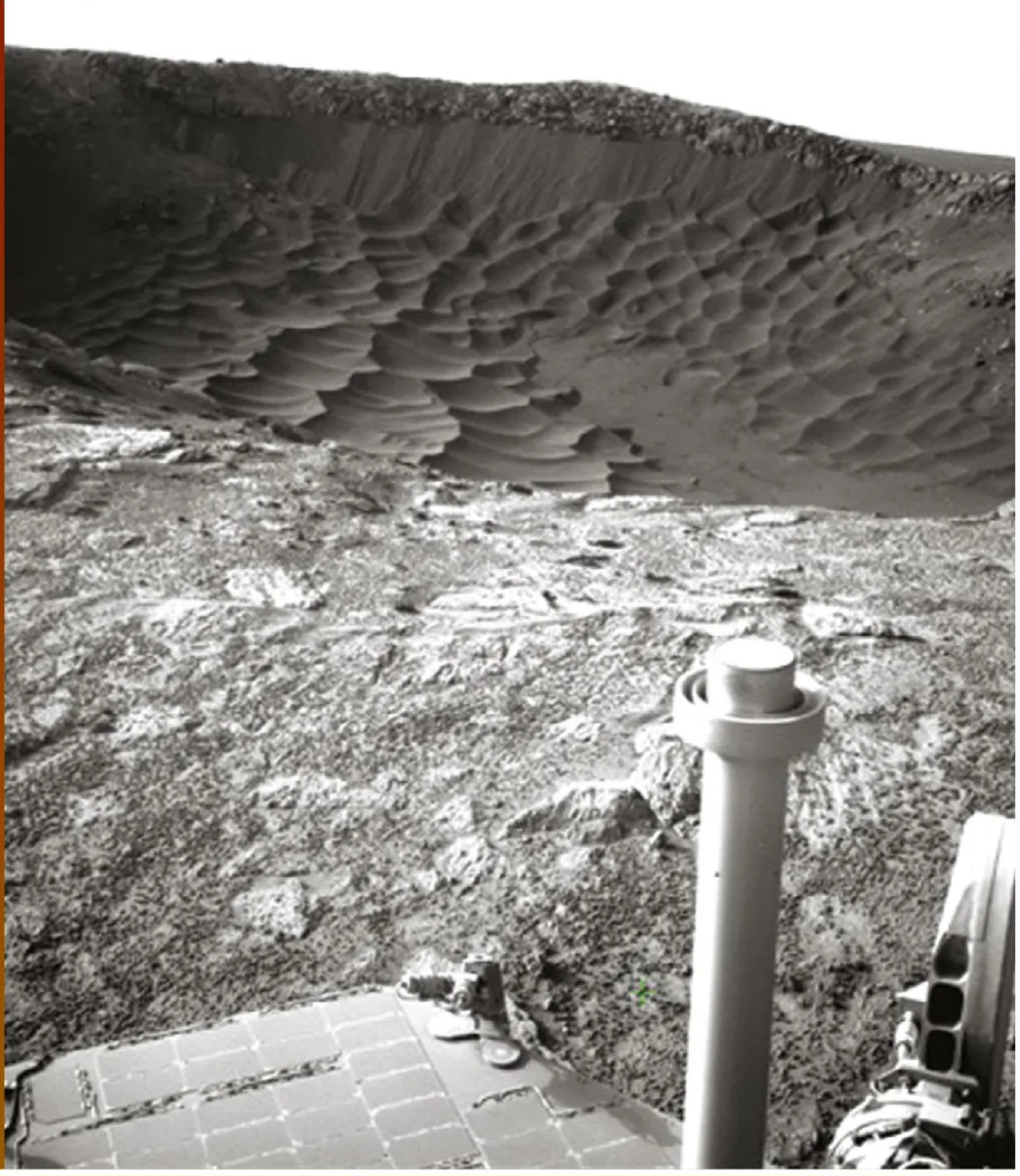
### Inspecting Marquette Island Rock

From November 2009 to mid-January 2010, Opportunity inspected this basketball-sized rock as NASA experts believed it might have originated deep in the Martian crust and been thrown to its present location by an impact event. The day before, the rover's abrasion tool had scratched a five-centimetre (two-inch) wide hole in the rock to help scientists learn more about its composition. It is named after an island in northern Michigan, US.

**2476 Sols**

### Textures of Santa Maria crater

This image from Sol 2476 shows just how different areas of the same crater can appear. In the background of Santa Maria crater the material appears smooth, while it is a lot more jagged in the foreground. The crater is about 90 metres (295 feet) in diameter and the rover was perched close to the rim of the crater on its southeastern edge when this photograph was taken using the navigation cameras (hence why it is black and white).



**0-3968 Sols**

# Opportunity's marathon

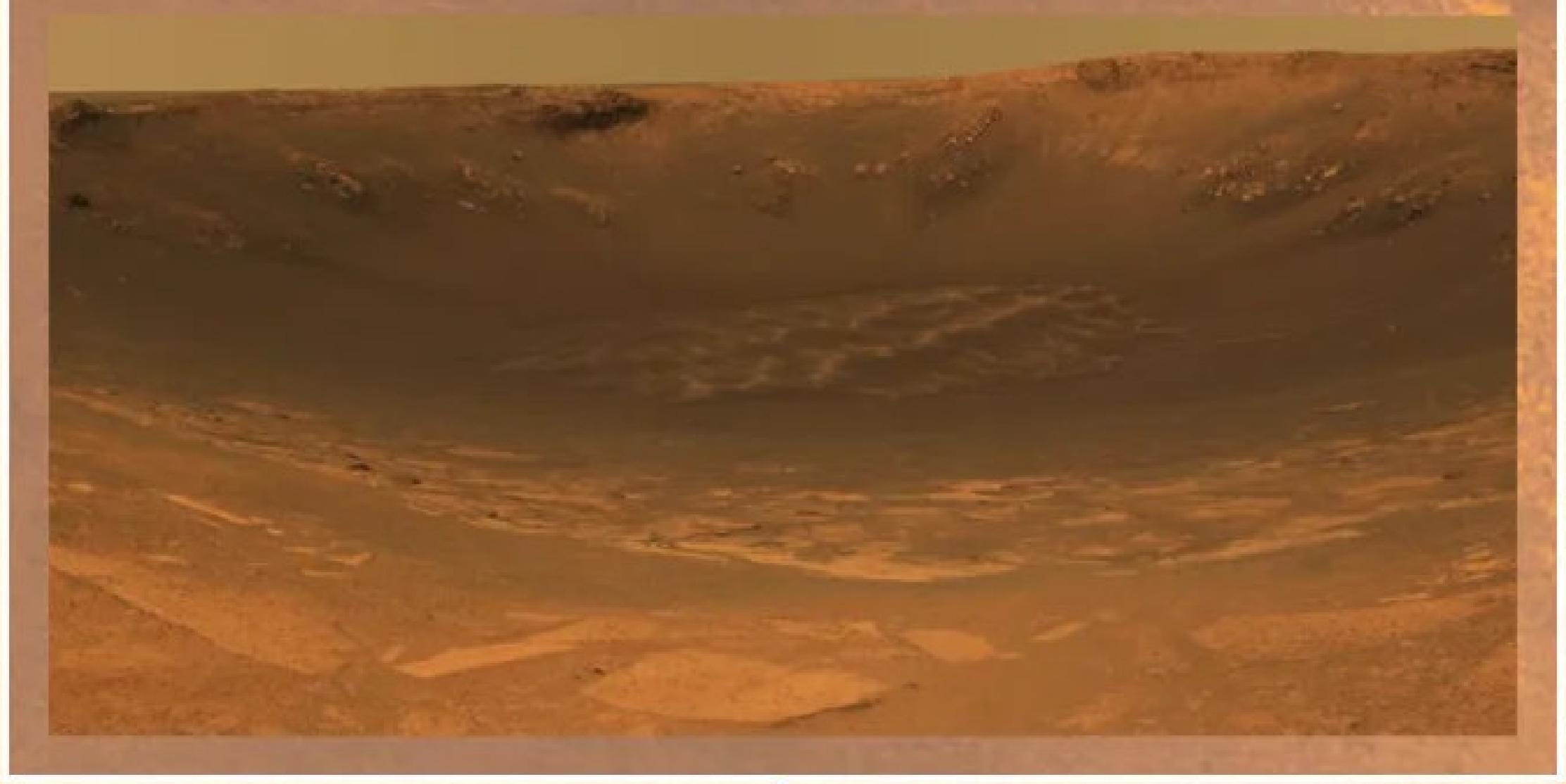
Opportunity's sheer tenacity means it has lasted a lot longer than mission controllers had originally envisaged. In 2015, after more than 11 years exploring Mars, the rover clocked up a total distance of 42.1 kilometres (26.2 miles) - the equivalent of running a marathon. On its journey from Eagle crater to Endeavour crater, it found signs of past water on Mars as well as clues as to the potential habitability of the Red Planet, including its salinity.

### 1 Eagle crater

Opportunity landed in this 22m (77ft) wide crater, just south of the equator, where it found signs of acidic water in the area's past.

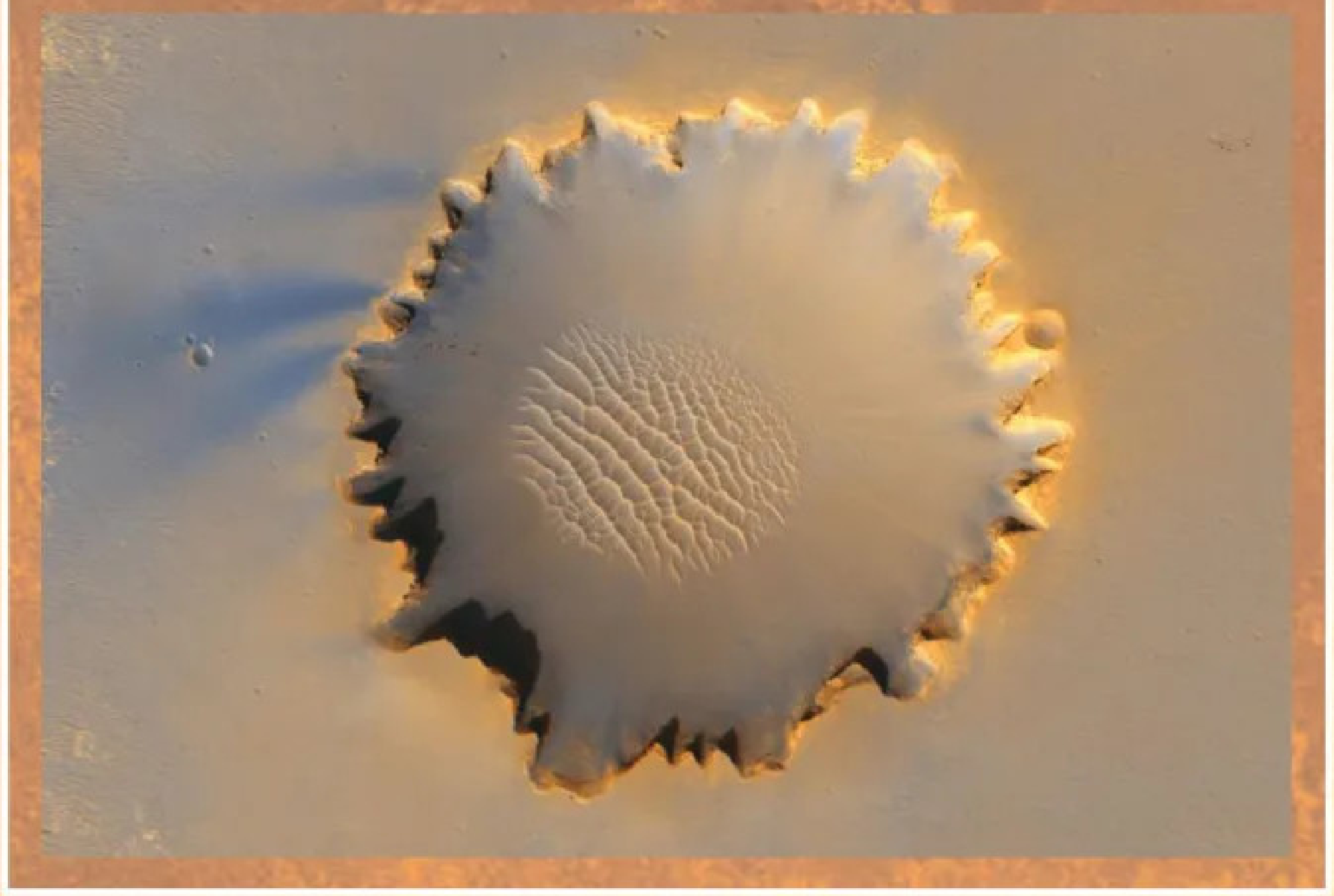
### 2 Endurance crater

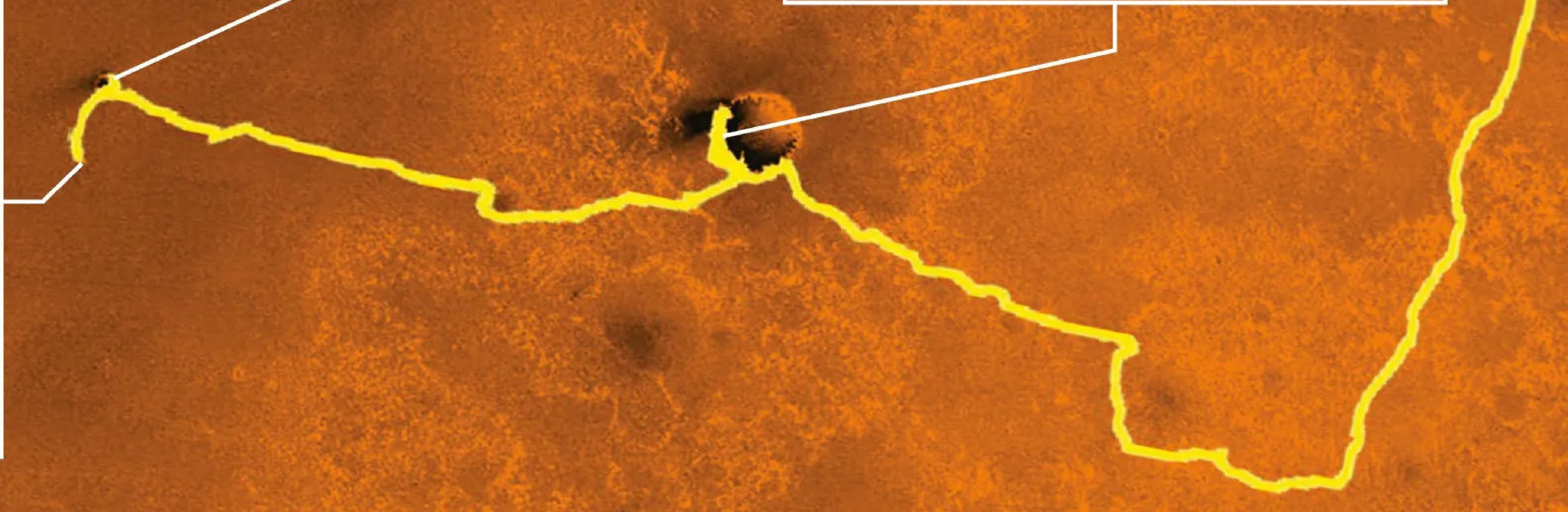
Opportunity spent May to December 2004 exploring this crater and found that liquid water was likely once present there.



### 3 Victoria crater

After 21 months on Mars, Opportunity reached this 730m (2,395ft) wide crater and it explored the crater's exterior and interior.

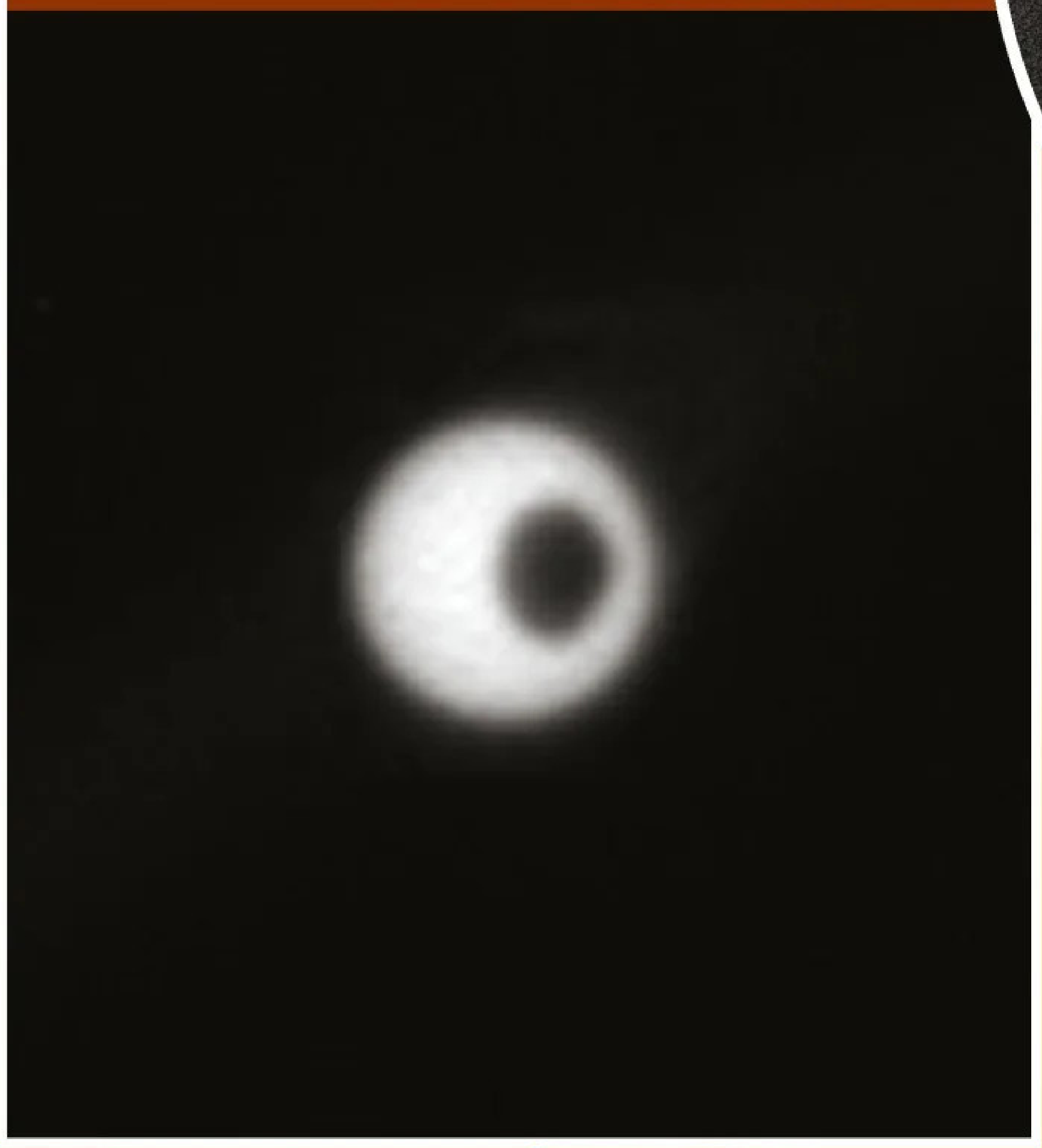




**3078 Sols**

### Transit of Phobos

On Sol 3078, Opportunity caught Mars' largest moon Phobos transiting the Sun. Technically it is an annular eclipse – the moon doesn't block out all the Sun's light. As the moon has an incredibly rapid orbit around Mars – just 7.6 hours – transits of Phobos only last around 30 seconds. However, they happen very frequently as the moon orbits close to the Martian equator.



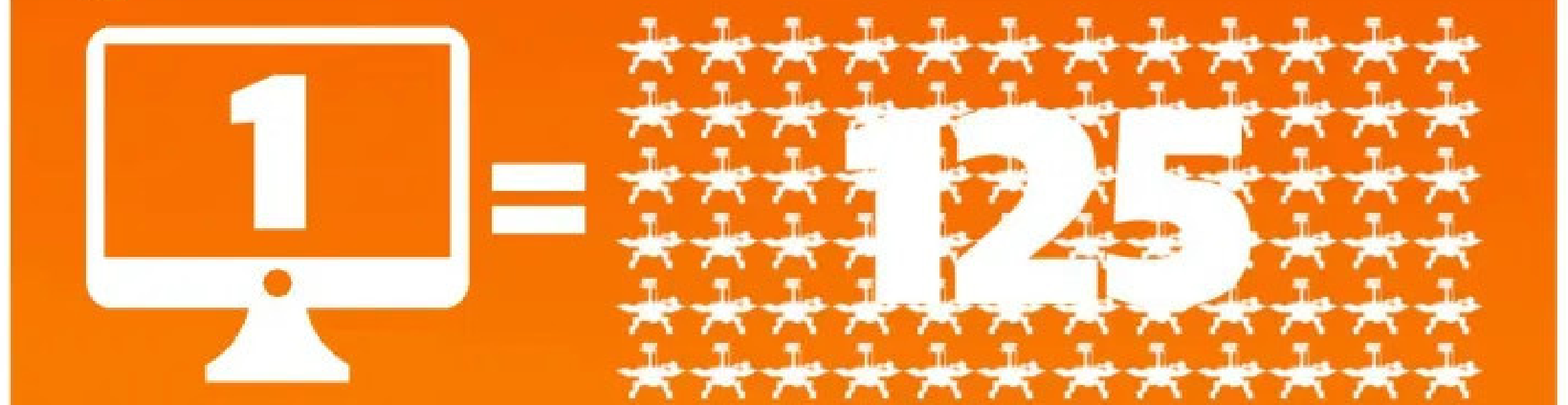
**3809 Sols**

### Snaps of a close comet encounter

Back in October 2014, mission scientists pointed Opportunity's cameras towards the sky and captured this image of the Comet Siding Spring. It was taken about two and half hours before the comet reached its closest point to the Red Planet. However, at that time, the Sun would have risen and made taking the photograph impossible. Some nearby stars, as well as effects of cosmic rays, can be seen alongside the icy denizen from the outer Solar System.

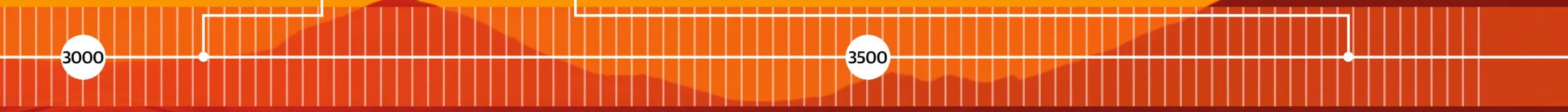
## Opportunity loses its memory

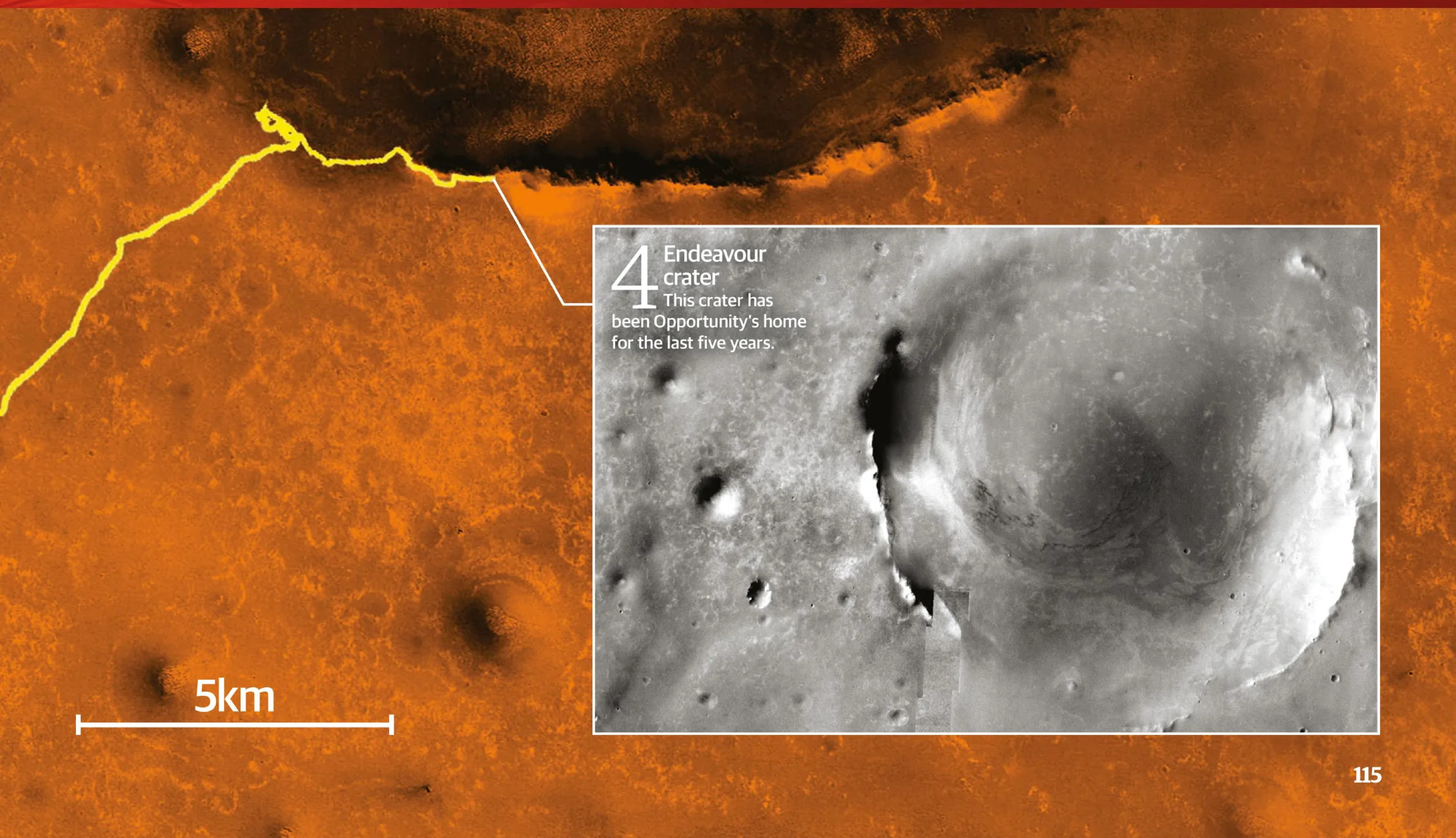
Over the years Opportunity has experienced several issues with its computer flash memory – a system which can store data even when the rover is turned off. In March 2015 mission engineers installed a software update, which they hoped would fix the issue. However, the problem recurred. The rover was only designed for a 90-day mission, and more than a decade of Mars exploration continues to take its toll on Opportunity's memory. Mission controllers must reformat the rover's memory banks whenever a glitch occurs.



**Opportunity's memory:** 128MB RAM
**Modern computer memory:** 16GB RAM

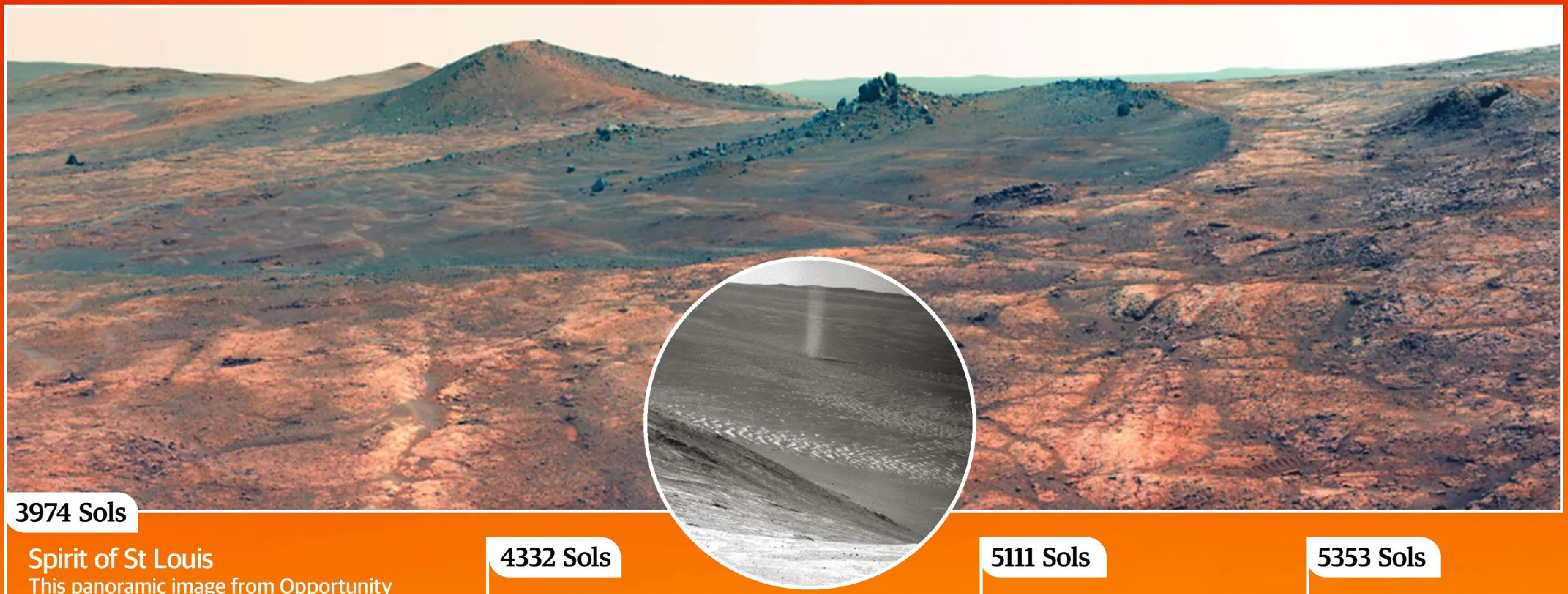
**Opportunity's camera pixels:** 1 megapixel
**An iPhone 7's camera pixels:** 12 megapixels





**4** Endeavour crater

This crater has been Opportunity's home for the last five years.



### 3974 Sols

### Spirit of St Louis

This panoramic image from Opportunity shows the elongated crater known as "Spirit of St Louis." Towards the centre is a spire of rock stretching upwards towards the Martian sky. The crater is 34 metres (112 foot) long and about 24 metres (79 foot) wide. The spire of rock is thought to be between two and three metres (6.6 and 9.8 foot) tall, meaning it sits slightly higher than the rim of the crater. The image was taken in late March 2015, around the time Opportunity was celebrating its 4,000th Martian day.

### 4332 Sols

### Dust devil spot

After climbing up Knudsen Ridge in the Marathon Valley, Opportunity looked back in the direction from which it came and spotted this dust devil spinning across the Martian surface. It was taken by the NavCams on Sol 4332 on the 31 March 2016. It was a pretty rare sight for Opportunity who hasn't seen as many dust devils as its counterpart Spirit. These events are caused by a rising and rotating column of air, which whips up the dust.

### 5111 Sols

### Last contact

On 10 June 2018, the final signal from Opportunity was received before it was engulfed by a planet-encircling dust storm. Unable to charge its solar panels properly, the rover entered hibernation two days later. Despite many efforts, NASA were unable to re-establish contact.

### 5353 Sols

### Mission ends

After sending over 1,000 signals to Opportunity in the hope of getting a response after the dust storm cleared, NASA declared the mission officially complete on 13 February 2019.

4000
4500
5000
5500

## Opportunity by numbers

**32°**

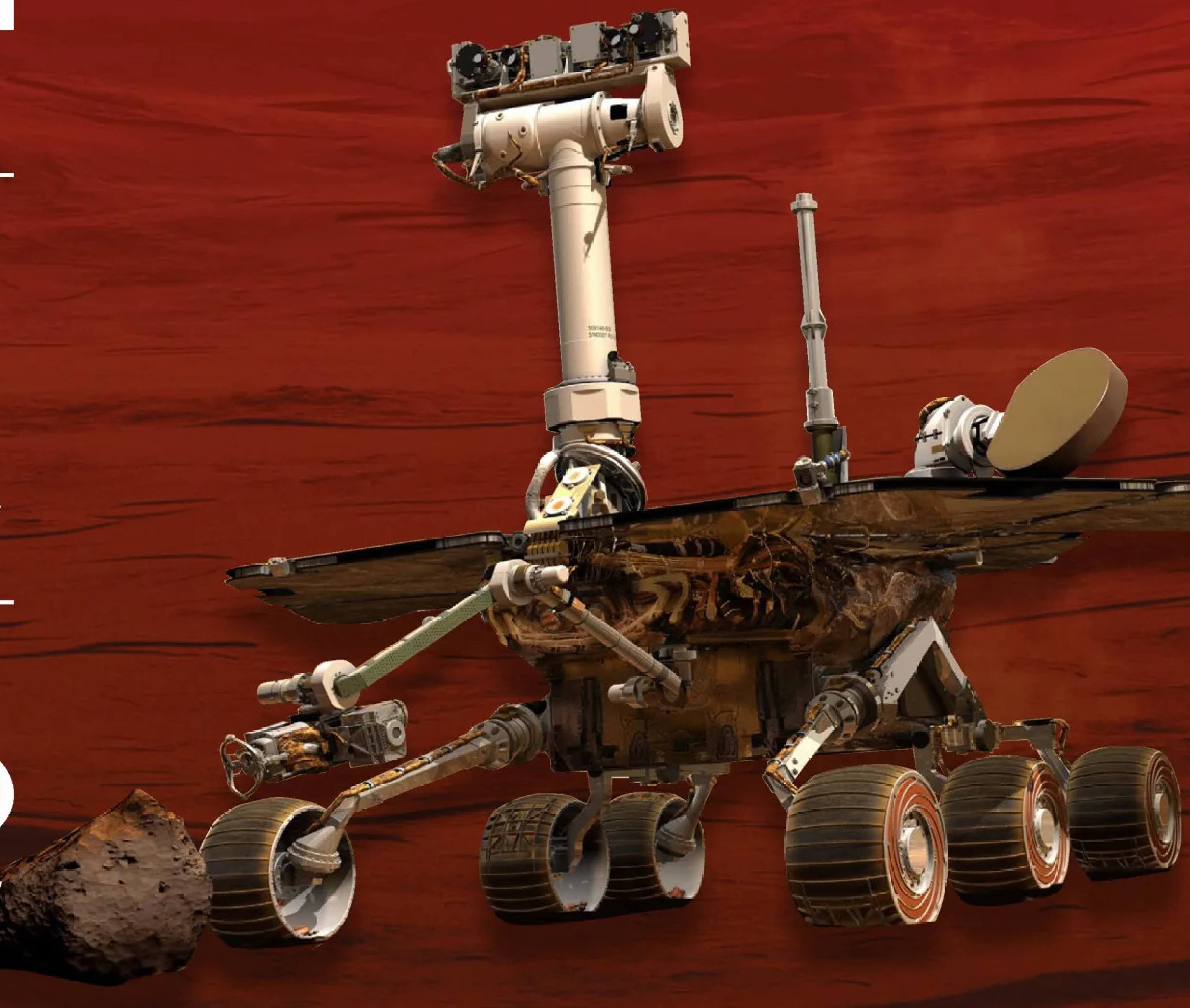
The steepest slope tackled by Opportunity during its visit to the Marathon Valley

**217,594**

The number of raw images captured by the rover's suite of cameras in its 14-year lifetime

**6**

Number of wheels on the rover, which allow it to trundle across the Martian surface



**45.16km**

The total distance travelled by the rover during its mission between 2004 and 2018

**185kg**

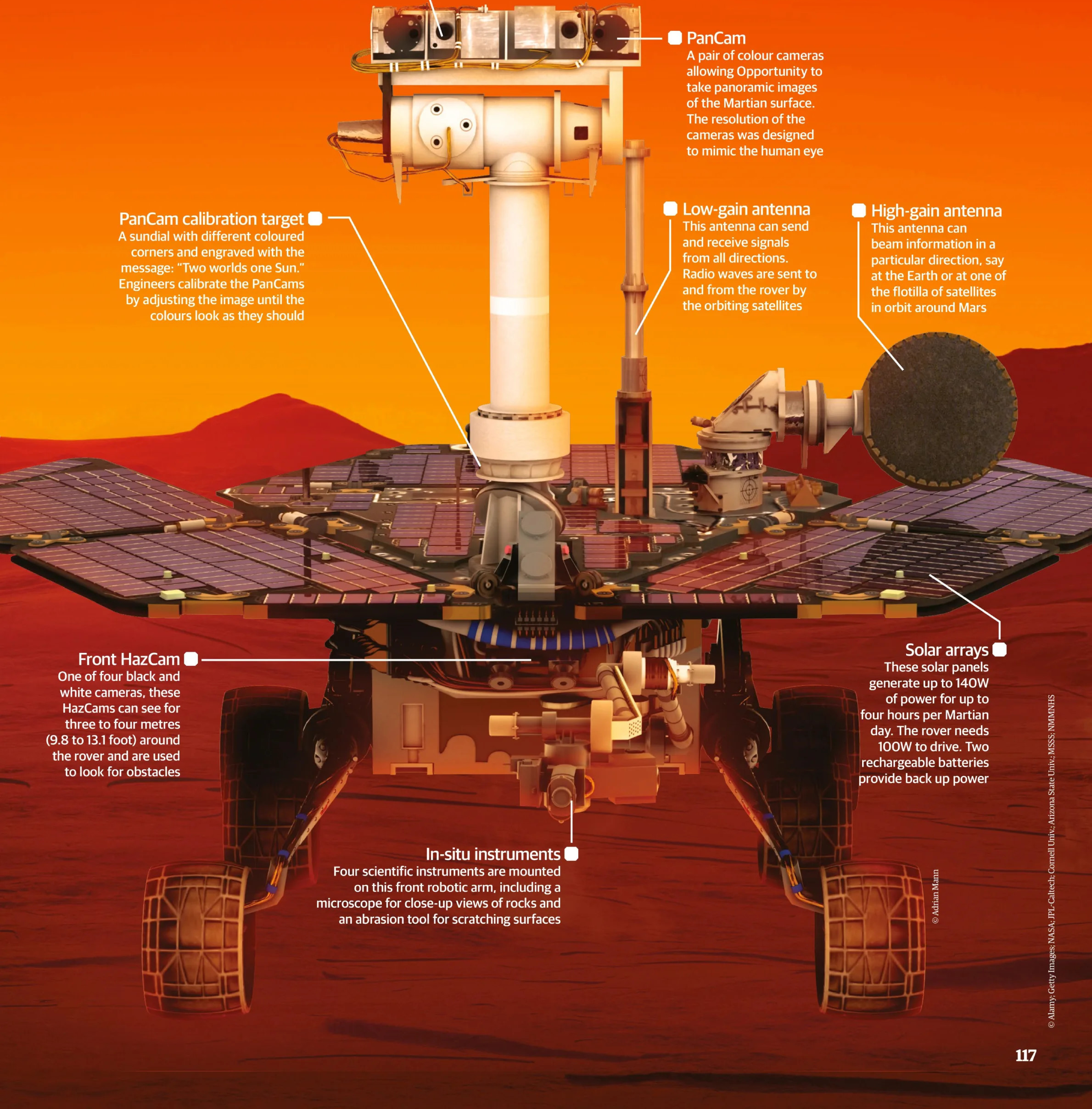
The mass of the rover – a little over the combined mass of two average humans

**0.18km/h**

The rover's maximum speed. That's about four-times faster than a snail's pace

# The anatomy of Opportunity

The equipment that helps Opportunity (and us) see the Red Planet



**NavCam**
A pair of black and white cameras mounted on the mast of the rover helps scientists to see the rover's surroundings and plan out its route across Mars

**PanCam**
A pair of colour cameras allowing Opportunity to take panoramic images of the Martian surface. The resolution of the cameras was designed to mimic the human eye

**PanCam calibration target**
A sundial with different coloured corners and engraved with the message: "Two worlds one Sun." Engineers calibrate the PanCams by adjusting the image until the colours look as they should

**Low-gain antenna**
This antenna can send and receive signals from all directions. Radio waves are sent to and from the rover by the orbiting satellites

**High-gain antenna**
This antenna can beam information in a particular direction, say at the Earth or at one of the flotilla of satellites in orbit around Mars

**Front HazCam**
One of four black and white cameras, these HazCams can see for three to four metres (9.8 to 13.1 foot) around the rover and are used to look for obstacles

**Solar arrays**
These solar panels generate up to 140W of power for up to four hours per Martian day. The rover needs 100W to drive. Two rechargeable batteries provide back up power

**In-situ instruments**
Four scientific instruments are mounted on this front robotic arm, including a microscope for close-up views of rocks and an abrasion tool for scratching surfaces

© Adrian Mann

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# The curious case of Cassini and Huygens

This dynamic duo travelled into the outer Solar System and completely changed our perspective of Saturn and its entire system

In 1982, NASA's two Voyager probes flew past Saturn and everybody stared with amazement at the images that they sent back. But for scientists, it only left a taste for more. So in the years to follow, NASA, the European Space Agency (ESA) and the Italian Space Agency crafted a spacecraft capable of exploring the mysterious ringed-world of Saturn and its many moons in order to return rare data back to Earth. This was the birth of the Cassini spacecraft, named after the Italian astronomer Giovanni Domenico Cassini.

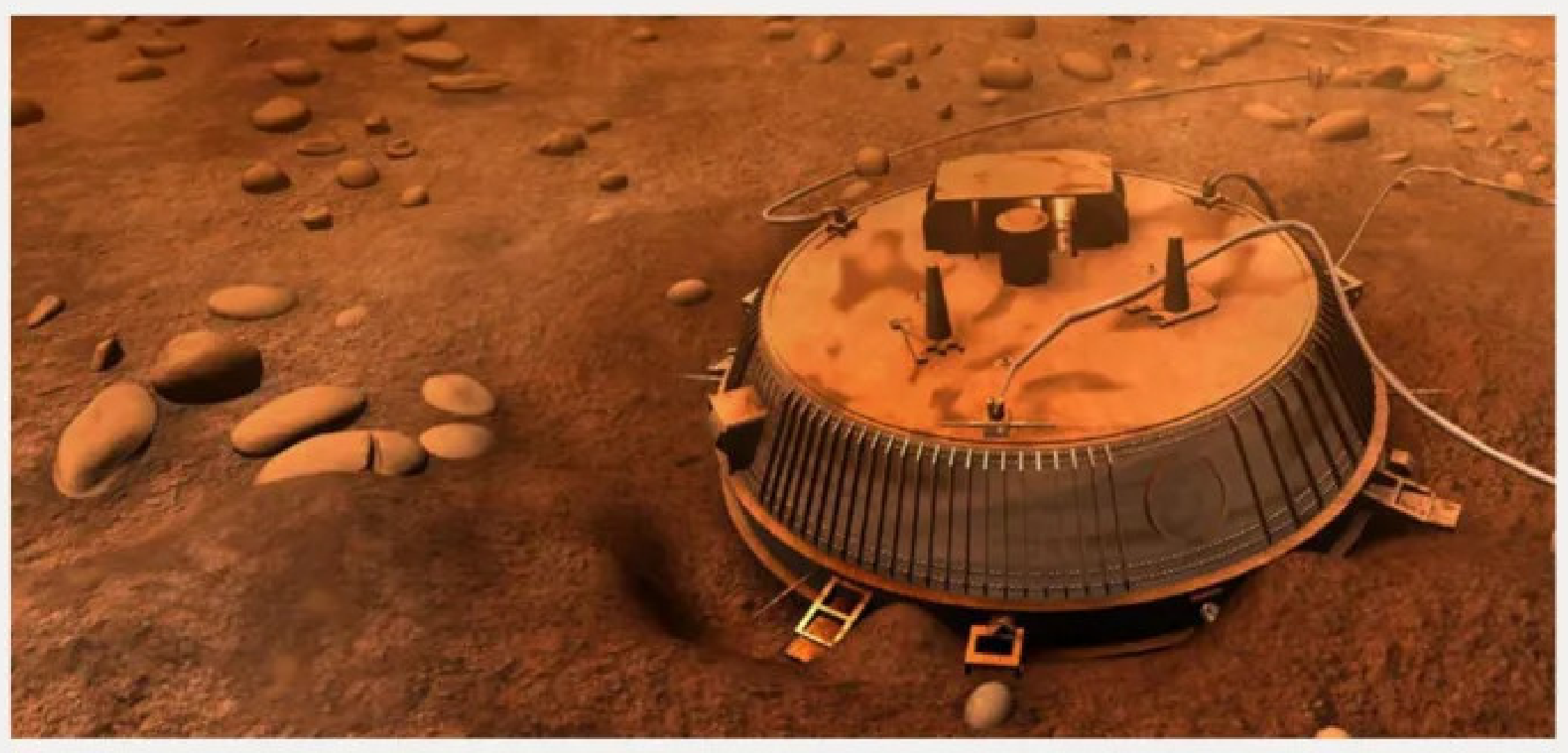
On 15 October 1997, the Cassini spacecraft and ESA's Huygens probe, which was designed to land on the surface of Saturn's largest and most elusive moon Titan, was launched from Cape Canaveral Air Force Station, Florida, United States, on the nose of a Titan IVB/Centaur rocket. This marked the beginning of an amazing scientific endeavour, preparing to gather unprecedented data about the mysterious gaseous planet that is Saturn and its surrounding system.

In order to make the journey to Saturn more fuel-efficient, the Cassini-Huygens spacecraft went through a number of 'gravity assists'. This is a manoeuvre that has been used by several spacecraft, and it consists of an object gathering momentum and speed through the act of passing close to a much larger object and being enticed by its gravity and slung into a greater speed. The first of these gravity assists came on 25 April 1998 when Cassini-Huygens flew past our sister planet Venus. Once again, the spacecraft orbited the Sun and returned for another gravity assist courtesy of Venus on 24 June 1999. After an additional gravity assist by Earth, Cassini-Huygens was then off towards the outer Solar System.

In December the following year, Cassini-Huygens arrived at the largest planet in the Solar System, Jupiter. There was already a manmade visitor at Jupiter in the form of NASA's Galileo probe. With the collective powers of these two spacecraft, scientists were able to gather unique data about the planet's turbulent gaseous atmosphere, diverse moons, thin rings and surrounding aura of charged particles.

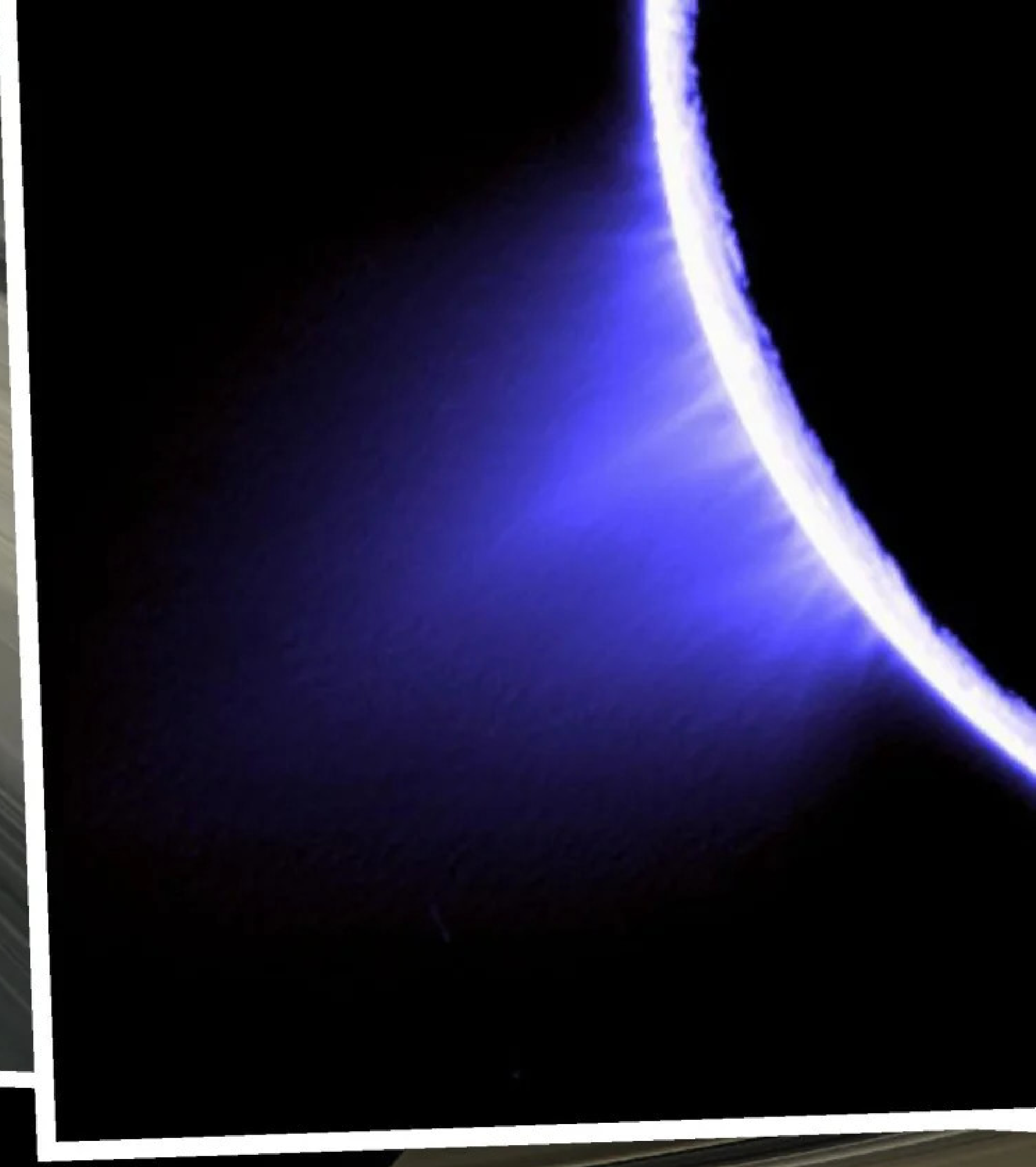
After the visit to Jupiter, Italian scientists took advantage of the fact that the Cassini spacecraft was on the opposite side of the Sun from Earth, separated by a distance more than one billion kilometres (621 million miles). This was a perfect opportunity to test Albert Einstein's famous theory of general relativity, which infers that an object as massive as our Sun can have such an outstanding gravitational attraction it can even warp light. Light in the case of this experiment was radio waves emitted and received between Earth and Cassini. Lo and behold, the results from this experiment confirmed this theory with a precision 50 times greater than any experiment before it.

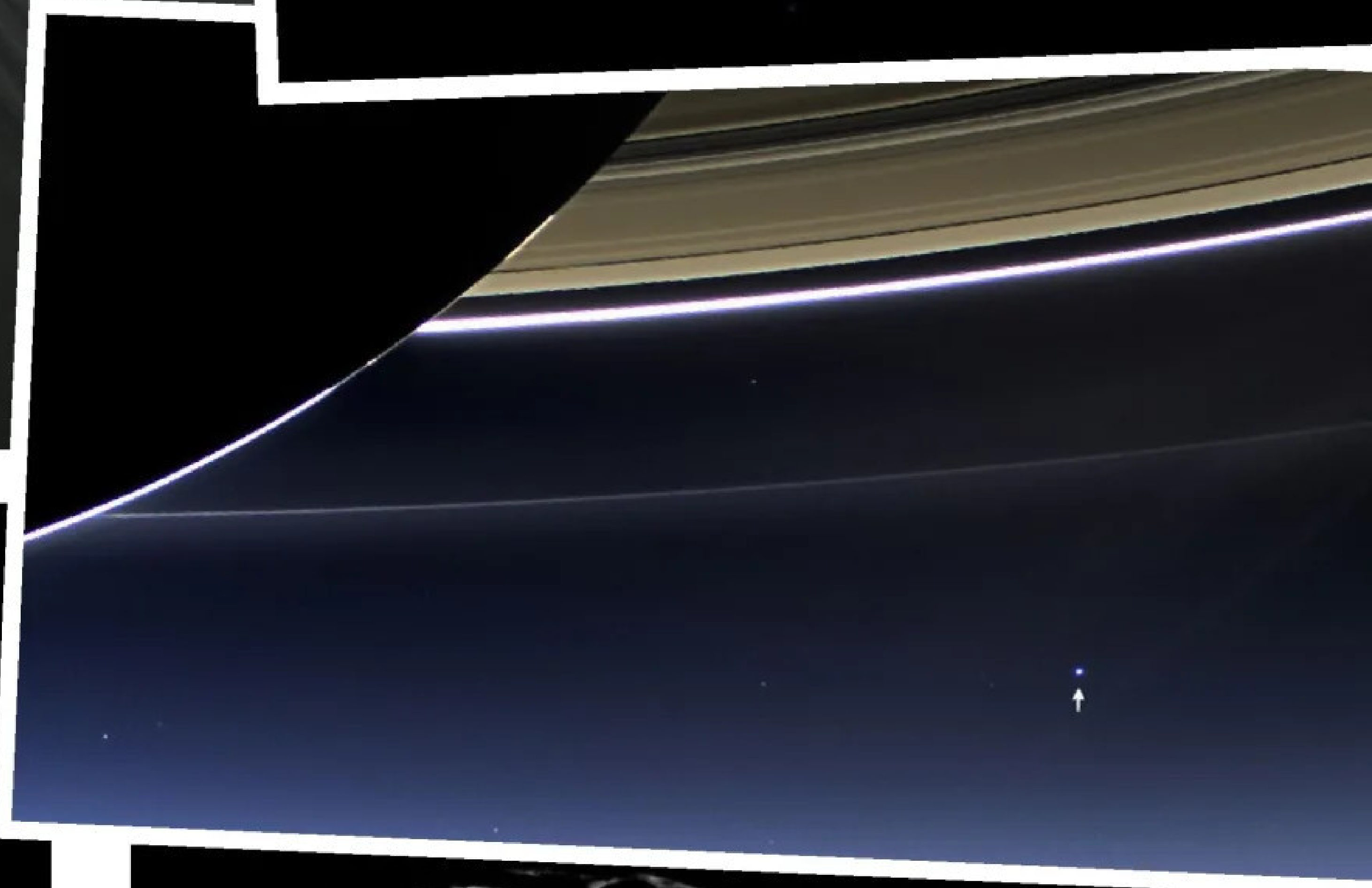
Cassini-Huygens kept making new discoveries and returned phenomenal data before it officially arrived at Saturn. For instance, on 31 May 2004 Cassini's Imaging Science System (ISS) captured images that revealed two new moons of Saturn, henceforth known as Methone and Pallene. Another landmark on the spacecraft's approach was the first of many moon flybys, which started with passing by Saturn's moon Phoebe at a distance of 2,000 kilometres (1,200 miles). Cassini took many high-resolution images, revealing an unusual brightness variation due to bright surface material and deep craters.

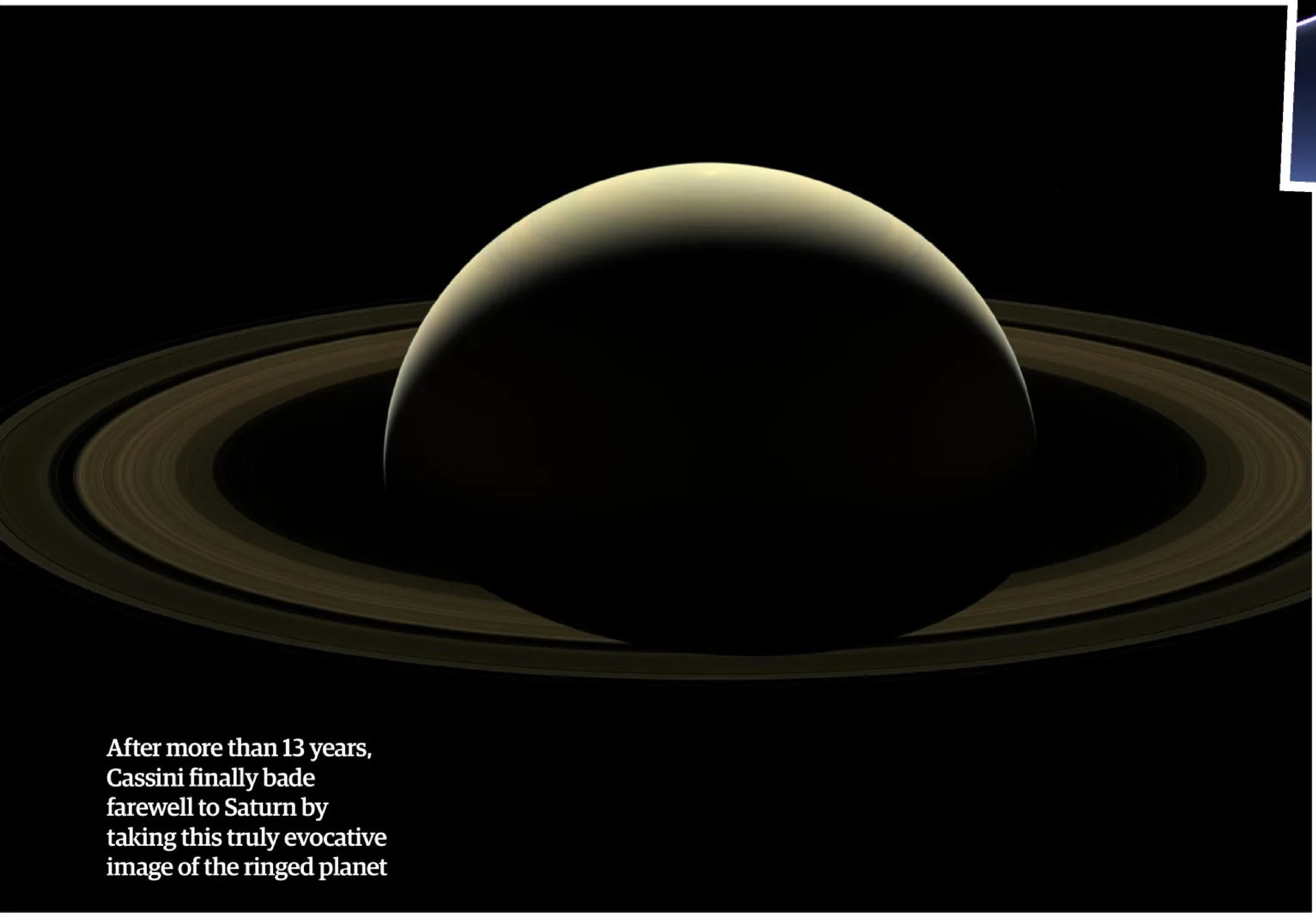


Liftoff of the Titan IVB/Centaur rocket that took Cassini into space

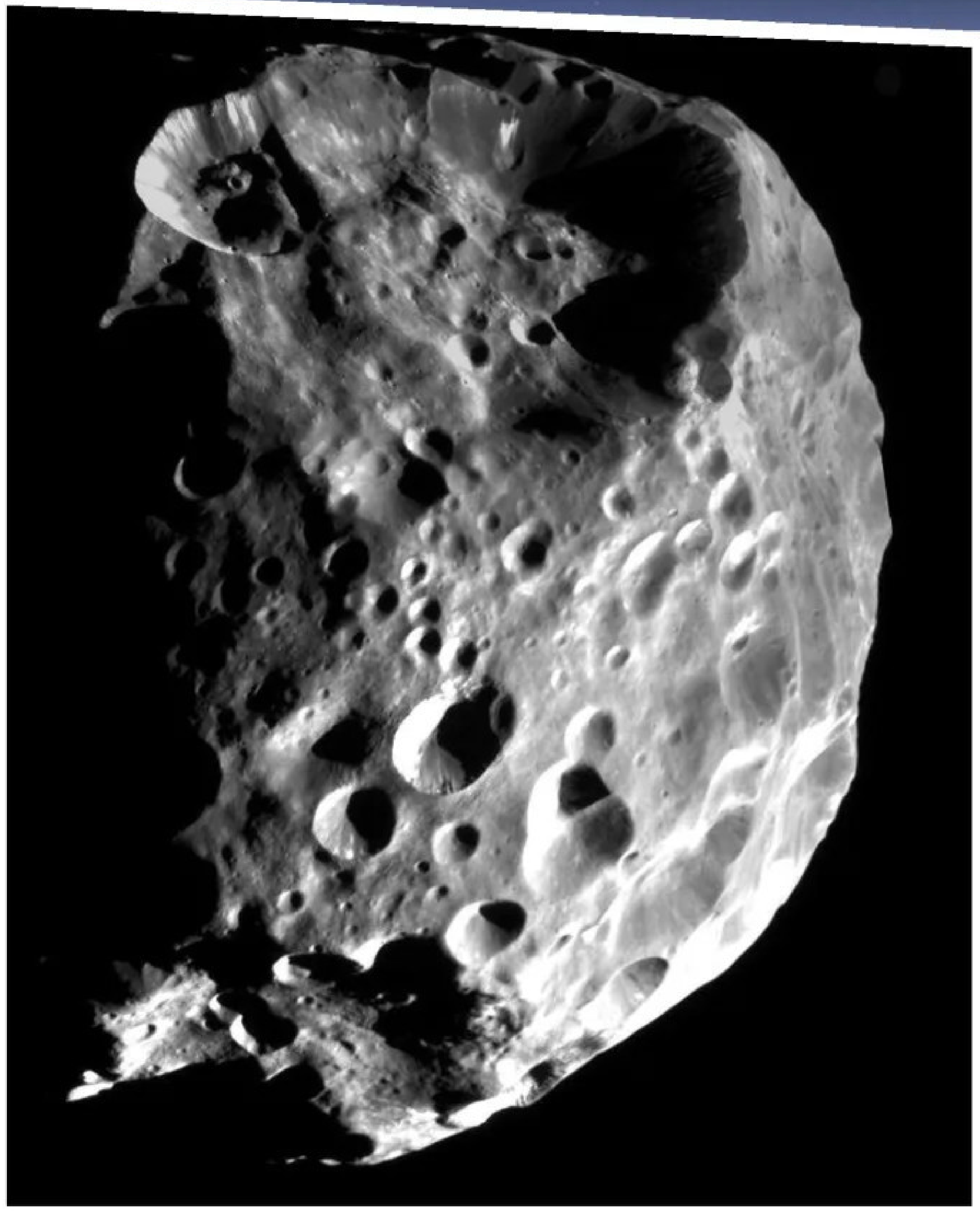
Cassini shown doing a spectacular dive between Saturn and its rings







After more than 13 years, Cassini finally bade farewell to Saturn by taking this truly evocative image of the ringed planet



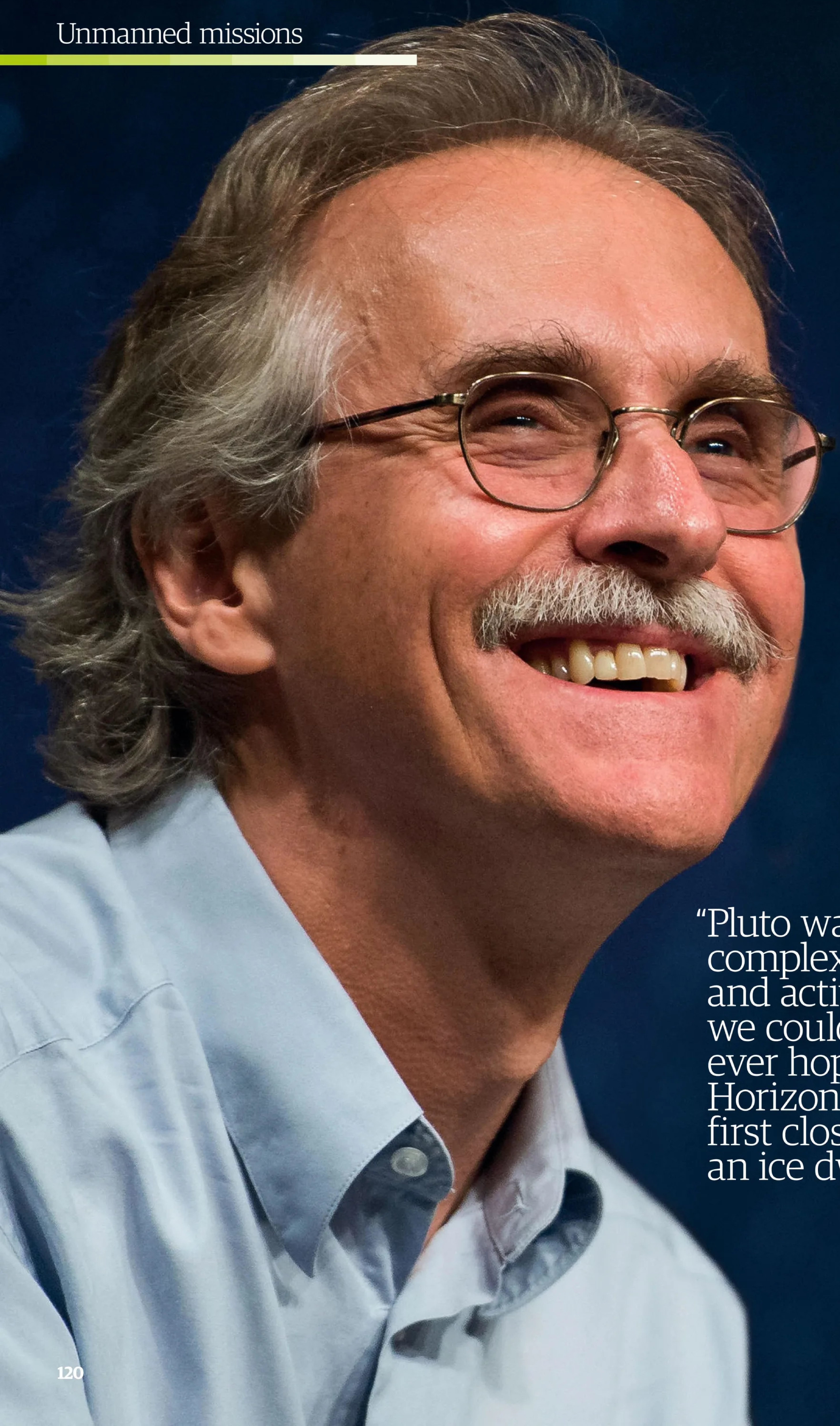
The day had finally arrived on 30 June 2004; the day Cassini, still carrying the Huygens probe, became the first spacecraft to orbit the sixth planet from the Sun, Saturn. The mission began a 13-year science extravaganza, with copious amounts of data transmitted back to Earth courtesy of the 12 scientific instruments on board the Cassini spacecraft alone.

In late 2004/early 2005, when the spacecraft came close to Saturn's elusive moon Titan, scientists detached the Huygens probe, which dived through the hazy atmosphere to land on its surface. The probe only lasted two hours and 27 minutes before it succumbed to the harsh environment. Huygens revealed that Titan resembles an early Earth in that it exhibits methane rain, erosion and drainage channels along with dry lake beds. Cassini was also able to image seas of hydrocarbons such as methane and ethane. This mine of rich organic material has made Titan one of the targets for future exploration.

Another of Saturn's moons that has become a target for future exploration, as it could contain life, is Enceladus. During its 22 flybys of the icy planet, scientists saw plumes of material erupting from the surface of Enceladus. Out of curiosity, scientists sent Cassini into these plumes, and the instruments found it to consist of water ice and volatiles. The only conclusion that can be drawn from these results is that beneath the icy surface, there is an ocean. This is due to the intense gravity of Saturn inducing an internal heating effect within Enceladus and melting its internal material.

Throughout the years, Cassini continued to collect game-changing data as well as marvellous images, including a particular one that was given the name 'The Day the Earth Smiled'. This was when Cassini, hidden in Saturn's shadow, snapped a silhouetted shot of Saturn in which, under its ring, can be seen the 'pale blue dot', also known as Earth.

The end was nigh for Cassini after the final flyby of the long-studied moon Titan. This final flyby completely changed the trajectory of the spacecraft so that it completed 22 dives through Saturn's famous rings. This closing chapter was given the name 'The Grand Finale'. When Cassini went through the gap in between Saturn and its rings, scientists found it to be unusually 'empty'. Scientists were expecting the Radio and Plasma Wave Subsystem (RPWS) to be bombarded with ice and dust particles, but there were only just a handful of pings detected. Unexpected results like this were why Cassini scientists were going to miss the spacecraft. It provided puzzling answers to long-held questions. Then on 15 September 2017, after almost 20 years in space, the Cassini probe came to its ultimate conclusion. With a final plunge, the spacecraft disintegrated in Saturn's upper atmosphere in a literal blaze of glory, thus bringing the Cassini spacecraft to a spectacular end.



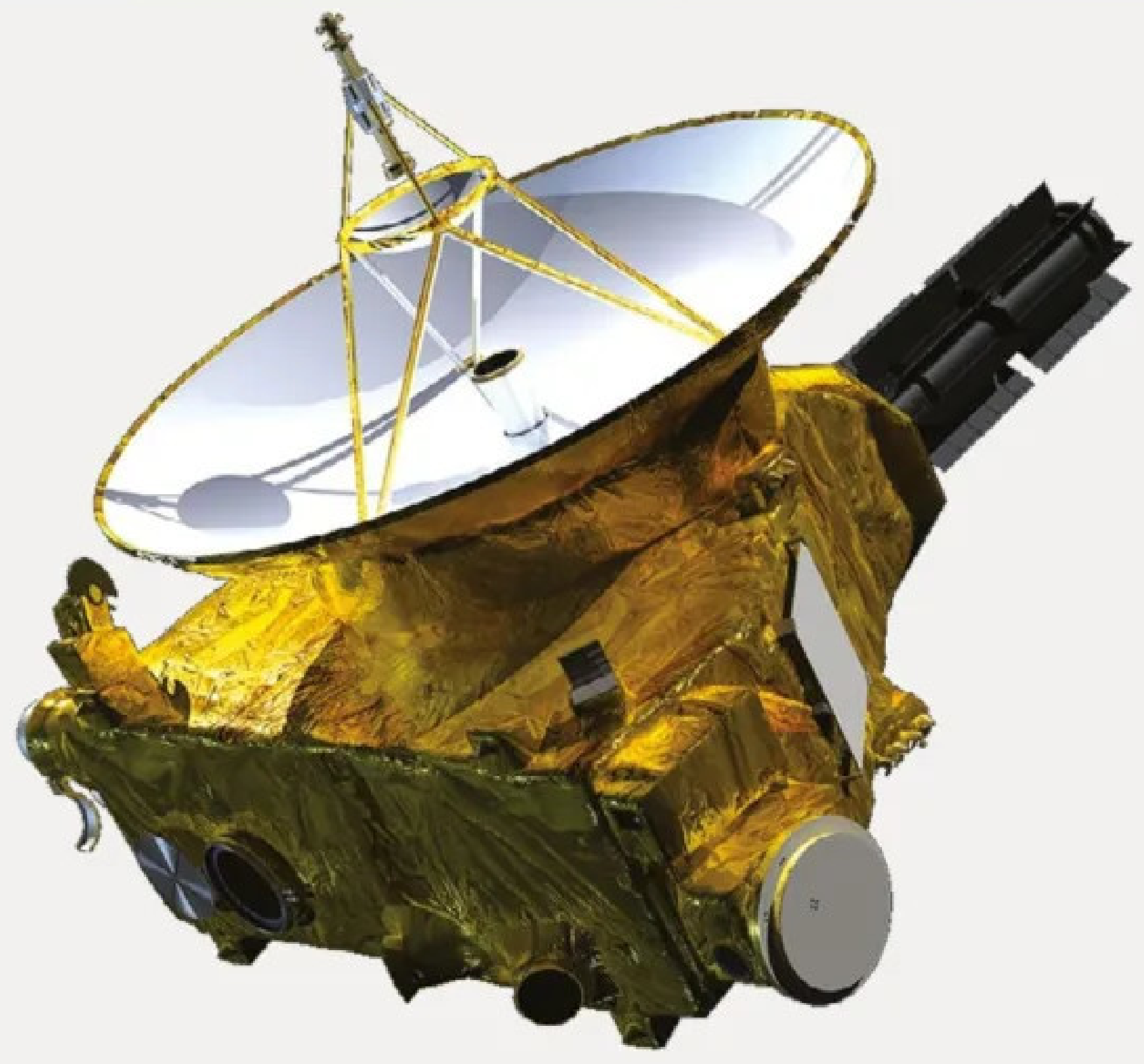
## BIOGRAPHY

**John Spencer**

John Spencer is a key member of the New Horizons mission that has been exploring the edge of our Solar System. The craft was launched in 2006 and successfully performed a flyby of Pluto in 2015, with Dr Spencer among the planetary scientists poring over the data. Born in Colne, UK, Spencer has a PhD in planetary science from the University of Arizona. He now works in the department of Space Studies at the Southwest Research Institute in Boulder, Colorado. He was a key figure in persuading NASA to extend New Horizons to 2021, and the probe is now set to delve deeper into the Kuiper Belt.

> "Pluto was far more complex, varied and active than we could have ever hoped. New Horizons was our first close-up look at an ice dwarf planet"

# *New Horizons:* Life after Pluto



## As the NASA mission was extended for further research, co-investigator John Spencer detailed his hopes for the next leg of the journey

**Interviewed by David Crookes**

**NASA has agreed to a mission extension for New Horizons to 2021. How are you feeling about that?**

Ecstatic. There is so much more to do with the spacecraft once we are beyond Pluto because the Kuiper Belt is an unexplored part of the Solar System. While Pluto is part of the Kuiper Belt, it's a very unusual member so we want to see what some of the more typical members are like.

When we detailed our proposal for New Horizons to NASA in 2001, we actually designed the spacecraft to be able to perform this extended mission. We made sure it would have enough fuel to divert to another project in the Kuiper Belt and get up close to it. To be able to do that is pretty thrilling.

**The space agency has been extending missions quite frequently. Is this something that could become the norm?**

Well, it depends. Sometimes a mission has a very specific, cut-and-dry purpose and, to be absolutely sure you can meet that goal, you build in a margin. You make sure the instruments will not only last the primary goal but probably a lot longer, so you want additional fuel in case you need it along the way. It's then likely that when you accomplish your primary goal, you will have resources left over that may allow you do a little bit more. In this case, it's a little bit different because we were planning from the start to have the capability to accomplish the extended mission further into the Kuiper Belt, and that meant, for instance, carrying a lot more fuel than we would have needed if Pluto was our only goal. We always knew we would be able to achieve our extended goal if we were funded to do so.

**Do you have to make any special arrangements for the extended mission?**

We are making changes. We're adding new people to the team who are experts in small Kuiper Belt objects and some people whose focus was very much on Pluto are leaving the team. We are having to negotiate additional time on the Deep Space Network, too, so we can continue to talk to the spacecraft and so on. So there's a lot of work to be done to make this happen but it's the kind of work we have been doing all along. That said, it is a bit of a different kind of mission that will require a different way of operating.

**New Horizons is now looking to reach 2014 MU69 by 2019. Is your entire focus on the destination?**

With Pluto we did very little science between the Jupiter flyby in 2007 and the arrival at Pluto in 2015. During that time, we would check out the spacecraft every year or so and we would check the instrument calibration, but we weren't really doing science. Instead, we were focusing that whole time preparing for the Pluto encounter, developing the science observations we wanted to do, and rehearsing them on the ground and on the spacecraft in some cases.

Now we will have one close flyby on 1 January 2019 with 2014 MU69, but before then we will be flying past a lot of other objects in the Kuiper Belt, seeing a much bigger range and getting useful observations of them as we go past. So there will a fairly continual sequence of observations scattered through [the period] and it will be a little bit more complicated because we will be doing more than one thing at once.

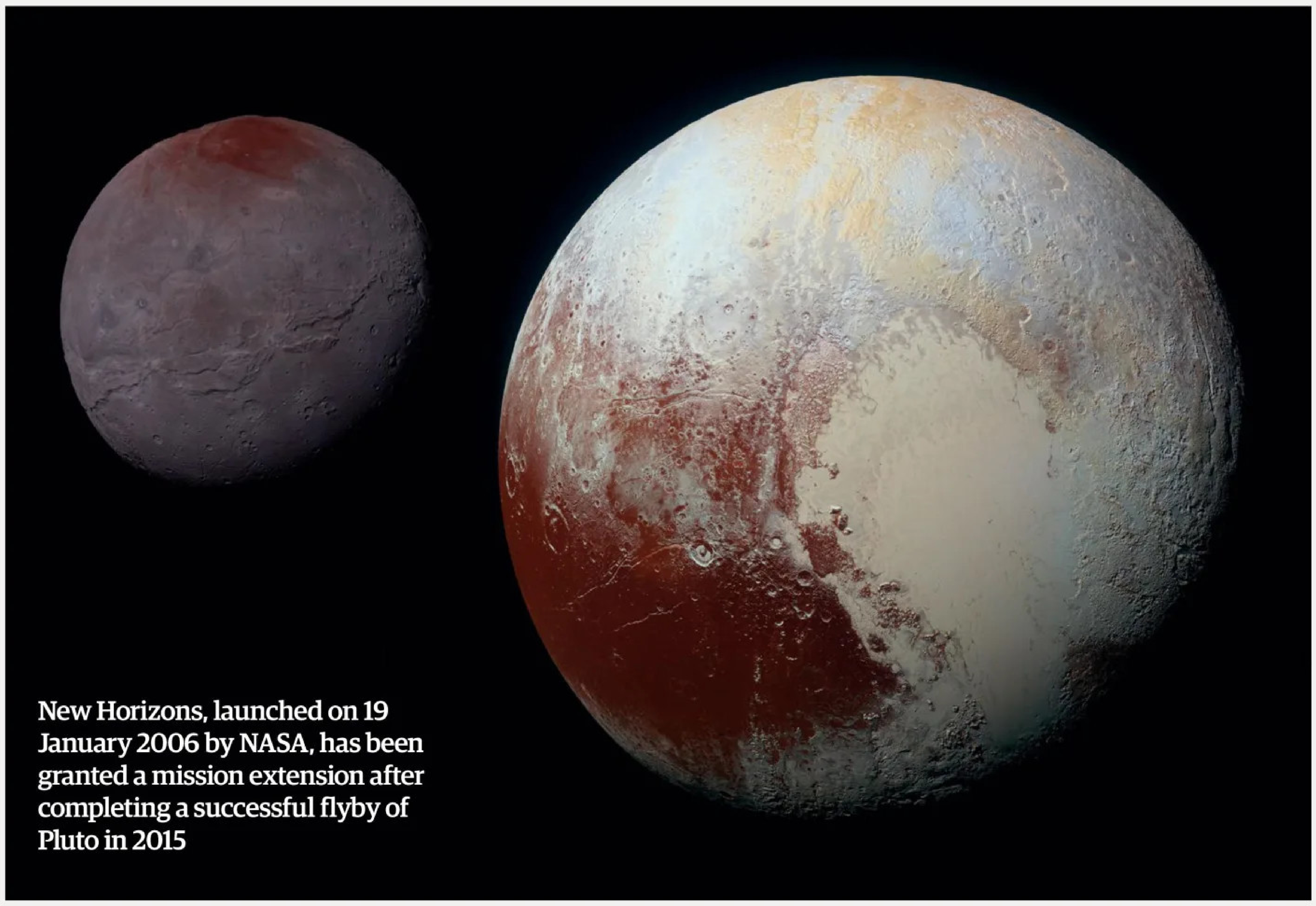
**Does the shorter time frame increase the pressure to get it right?**

Well, we only have 2.5 years to prepare for this rather than having eight years or so between Jupiter and Pluto, so we do need to work on a much more accelerated schedule. But that will be possible because we have the mechanism in place for how to plan observations and we have all the software needed to test them and so on. It means we will be able to do everything we want, but we will have to do them a lot faster than we did when we were preparing for Pluto.

**What are you hoping to find along the way? What will New Horizons be looking out for?**

We will be observing about 20 distant Kuiper Belt objects. We won't be close enough to see the detail on their surfaces but we will see them as points of light against a star background and we will be able to observe them from different angles as we fly past. They will look brighter on approach because we will be seeing the sunlit side and they will look dimmer as we go past because we'll be looking back at the crescent of these objects, so it's a bit like the Moon going through its phases. The rate at which the brightness fades as we go from looking at the sunlit side to the dark side will tell us a lot about what the surfaces of these objects are made of, how rough they are and whether it's fine powder or more rocky.

It will also allow us to compare the different objects because we will see different kinds of Kuiper Belt objects flying past. We can use this as a way of



New Horizons, launched on 19 January 2006 by NASA, has been granted a mission extension after completing a successful flyby of Pluto in 2015 classifying them and we will be able to compare their behaviour to 2014 MU69 and see how typical it is.

**So 2014 MU69 is the only one you'll see close up?**
It is, although we'll be close enough [...] that we'll be able to look for moons or even rings around them. Even though we only have a little eight-inch telescope on the craft, we will be able to see more detail than Hubble, simply because we are so much closer and that will be a useful contribution.

**What are you watching out for?**
We will watch the brightness changing as the objects rotate so we will learn about rotation rates and things like that. But with 2014 MU69, we will be getting up to 3,000 kilometres [1,860 miles] distance and we will be filling the frame of our mirror-angled camera with the object and seeing lots of surface detail – craters and fractures and boulders and who knows what else we might find? We will be taking colour images and mapping the composition of the surface in infrared and we will be looking for any signs of gas that might be coming off it. That said, we don't expect to see gas because this object has been in a stable orbit for a long time and it should have lost any gas that might have come off by now. But we want to be prepared for anything because we have certainly been surprised many times in the past.

NEW
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When New Horizons was being prepared, scientists ensured it could go on for longer than its primary goal of reaching Pluto

**Why the focus on the Kuiper Belt?**
It is a completely new class of object. There are hundreds of thousands of objects the size of MU69 in the Kuiper Belt and it is the least disturbed region of small bodies in the Solar System. The asteroid belt, by contrast, has been very much stirred up by the gravity of Jupiter and there have been lots of collisions between objects in the asteroid belt, so there are lots of interesting things to learn there.

But it is very different from how it was when comets formed in the outer Solar System and were perturbed back into the inner Solar System. Those lost a lot of ice and gas and they are of a different form to how they started out as well. But these bodies out in the Kuiper Belt have been there for billions of years with very little happening to them since they were part of the formation of the Solar System. This means we can learn a great deal about how the Solar System formed and how these small bodies came together to later make larger planets. We won't be able to learn this elsewhere so we are very excited to see these objects up close.

**You're also going to be looking at Eris, the dwarf planet that was discovered in 2005, aren't you?**
Yes, even though Eris is further from New Horizons than it is from the Earth. But we have an opportunity here because we are looking across the Solar System to the other side, which means we can look at Eris from a different angle than is possible from Earth.

The Earth is so close to the Sun that you can only ever look at a full disc and Eris is always seen fully illuminated. From New Horizons, we can look at it further away from the Sun and we will see how it scatters light from other angles. That will tell us more about what the surface is made of. But yes, we are 100 astronomical units [one astronomical unit is the distance from Earth to the Sun] away from Eris so it's a little odd that we can do new science from further away than we were when we started the journey in 2006. But we'll have this unique perspective that will hopefully give us some new insights into what the surfaces of these objects are like.

"We'll be close enough to these Kuiper Belt objects that we'll be able to look for moons or even rings around them"

Dr John Spencer of the SwRI (left), Dr Jeffrey Moore of the NASA Ames Research Center (middle) and Dr David Grinspoon of the Planetary Science Institute (right) discuss New Horizons in Washington, DC

**Is this the kind of opportunity that you stated in your case to NASA?**
Yes, absolutely. The proposal that we wrote in the spring and that NASA reviewed and approved pretty much laid out these arguments. This is what we think we can do, these are the objects we think we can look at, and this is what is unique about what we can do compared to what we can do from Earth. In some cases, it's simply because we can look from a different angle.

**What would have happened without the funding?**
If for some reason NASA had not been able to fund us, we would not have been able to pay for the time of the engineers to design observations, or for the Deep Space Network to talk to the spacecraft, and that would have been the end of the mission. But the spacecraft is continuing on, faster than escape velocity from the Sun, so it won't slow down much more and it will continue out of the galaxy whether we talk to it or not.

**Obviously, New Horizons made a successful flyby of Pluto. What are the key discoveries?**
Oh, boy, there were so many. It was just an amazing place to visit and far more complex, varied and active than we could have ever hoped. We saw so many things we couldn't have possibly imagined before we got there: giant ice mountains and this enormous sea of frozen nitrogen that is convecting and flowing; glaciers and huge areas covered in dark organic material. It was our first close-up look at an ice dwarf planet and just seeing a different kind of world and features we had never seen before was amazing. So now we are just trying to figure out what it all means.

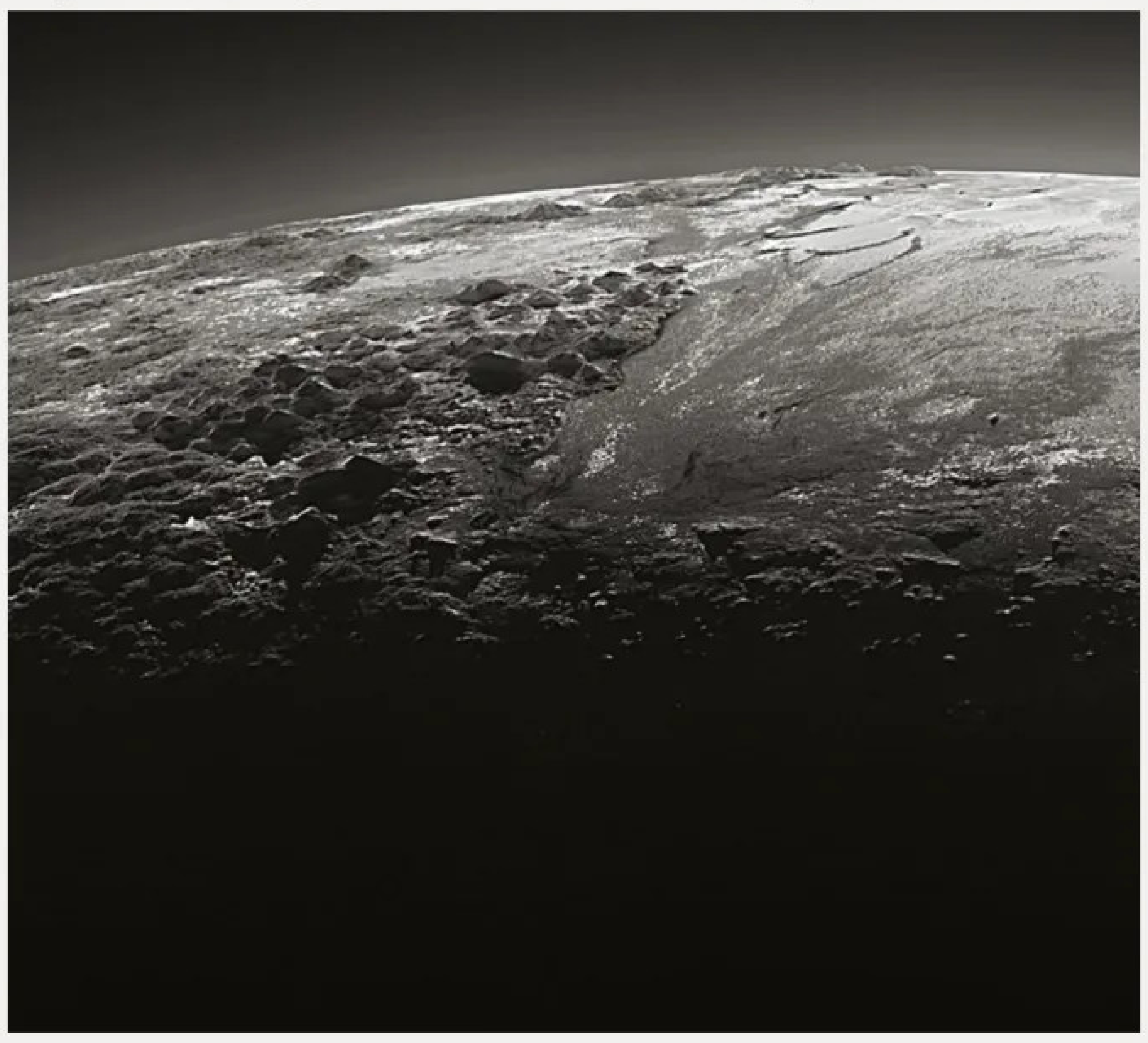
**Was there anything particularly striking?**
One of the striking things has been that a world as small as Pluto is still producing a remarkable variety of phenomena, with lots of geological activity that is continuing to this present day. But there isn't a giant planet nearby that could distort it and heat its interior through friction, which is how a lot of the moons of the giant planets are heated and come to have geological activity. So it's intriguing that the little bit of radioactive heat from the rock inside Pluto and the little bit of leftover primordial heat is enough to power remarkable geology.

We also thought that the atmosphere was escaping into space at a rapid rate because that is what our calculations were suggesting, but when we got to Pluto we found that we were wrong about that. It is losing its atmosphere to space but 100 times more slowly than we expected, so the atmosphere was full of surprises as well. It was just an amazingly successful mission and we have learned a huge amount about Pluto as a result of that.

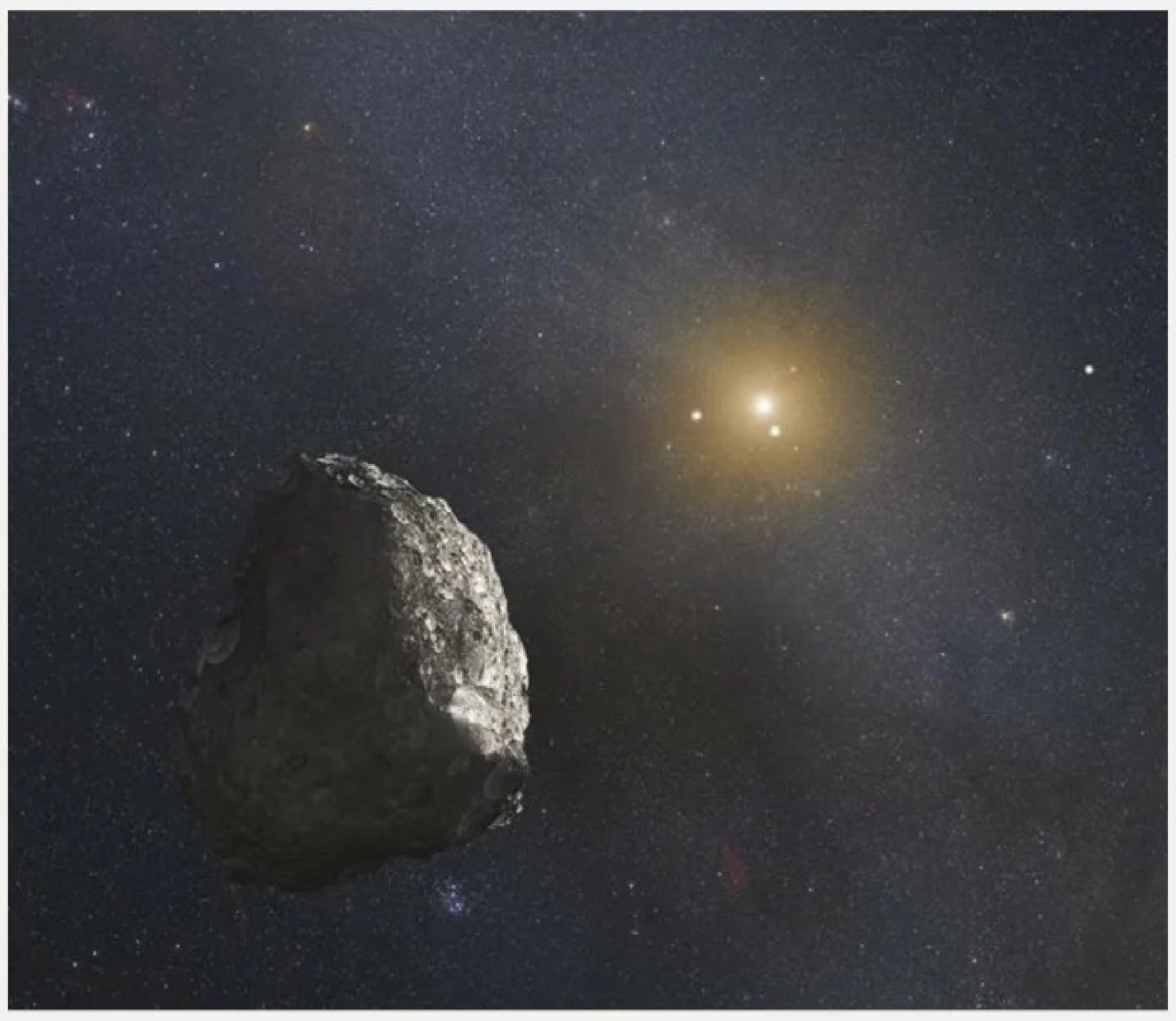
**Is the data continuing to surprise you?**
We have got 80 per cent of the data down and we prioritised it so that the closest and the best pictures came down first. What is coming down now is the rock pile – all the distant images and the bits of sky that don't have Pluto in them, which may show some objects orbiting Pluto such as rings and things. That's still going to be interesting but it's the lowest priority stuff. Having said that, we are continuing to find surprises in the data. We are busy writing papers now and getting them published and also preparing the data for public access. Right now, most of the data is accessible only to the team, but in October we will be submitting most of the data with good calibration and documentation and so on to NASA's planetary data system, where it will be archived for anyone to access the data and do research on it and draw their own conclusions.

The New Horizons team are all smiles as they review newly processed images from the spacecraft

Shortly after its closest approach in 2015, New Horizons captures the icy mountains and flat ice plains of Pluto



An artist's impression of a Kuiper Belt object on the outer edge of the Solar System



**Is there life for New Horizons beyond 2021? Where else could it go?**
The main focus beyond 2021 will likely be the solar wind. We're getting into the outermost part of the Solar System where the solar wind is slowing down and it will eventually run into the interstellar winds, so you'll get a transition there. This is a region that has been explored by Voyager 1, which was launched in 1977, and which is currently about three-times further from the Sun than even New Horizons. But while we are following behind Voyager, we have more sophisticated plasma instruments so we can learn more details about that transition and how the plasmas are interacting in that outermost part of the Solar System. We could also find additional objects that we can photograph out there. They probably won't be ones we can get close to but there may be more distant observations that we can make.

**So we can expect lots of cool pictures?**
Well, we don't currently know of any objects out there that we could observe with our cameras, so it's likely we won't be using our cameras and our spectrometers at that point but instead will be focusing on the plasma instruments. But all of that is subject to getting another extension from NASA, which we won't be proposing for a few years and which will be a different kind of mission. But we expect to talk to the spacecraft until some time in the 2030s because it should still have enough power to run its transmitter, send us data and receive commands. So I think, if we get the funding, there will be a long and interesting mission for New Horizons beyond this current extension.

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# What has NASA done for you?

# Hundreds of billions of dollars have been spent on space exploration, but take a look at what we got in return

**Written by Laura Mears**

Space exploration is expensive. The Soviet Union kick-started the Space Race in 1957 when they placed the first ever artificial satellite into orbit: according to NASA historians, the beachball-sized Sputnik 1 caused a "full-scale crisis". The idea of falling behind with technology in the middle of the Cold War frightened the American public, and the US government responded with heavy investment. By the end of 1958, NASA had been formed. Over the next decade, the government would pour more than $25 billion (£16 billion) into the space programme to ensure that the first man on the Moon was American, and in the decades that followed, hundreds of billions of dollars would be spent pushing the boundaries of science and technology. This phenomenal investment won America the Space Race, and it has completely changed our understanding of the universe, but with NASA currently operating on a budget of around $18 billion a year and estimated to have spent at least $500 billion (£326 billion) in the last 60 years, what does it mean for average people? What has NASA done for us?

The obvious answers would involve satellites, weather monitoring, communications, navigation and aeroplane travel, but even the Apollo missions, the Space Shuttle programme, and the exploration of Mars have benefitted the general public. When NASA was formed, part of the conditions of its funding included a requirement to share new advancements with industry, and behind the dramatic launches and the mind-blowing photographs, NASA spin off products have been taking space technology and adapting it to solve everyday problems. One of the most notable is memory foam, developed at the Ames Research Center in 1966 to protect aircraft pilots and passengers in the event of a crash. It is now a household item, used in sports helmets, protective clothing, high-end mattresses and prosthetic limbs. But there have been more than thousands of others.

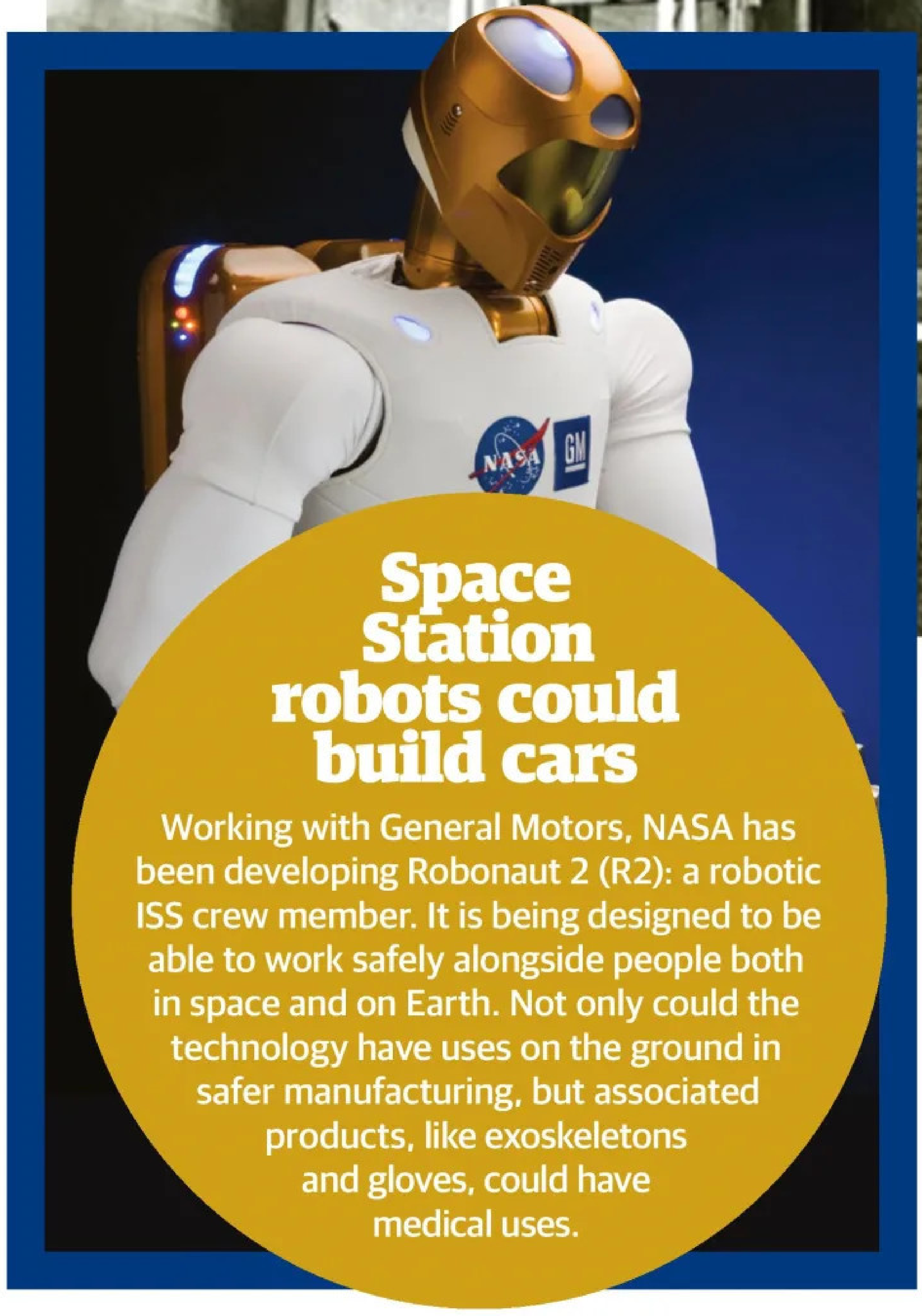
The Mercury missions, which took American astronauts into orbit around Earth for the first time, brought innovations in waste disposal. The Gemini missions, which developed the technology required for the Moonshot, inspired anti-glare coatings for television screens and computer monitors, equipment to measure patient oxygen and carbon dioxide levels, and advances in oil mining technologies. And, the Apollo programme itself spawned dozens of new ideas. The heat shielding technology used to protect the Apollo spacecraft was adapted to develop paints and foams to protect aircraft, and later used to create layers of insulation to slow the rate of fire damage in public buildings.

The digital image processing software developed to allow Apollo astronauts to land safely on the Moon was later used as the basis for the first of the Landsat satellites. Together, this series of satellites have been capturing images of the Earth for over 30 years, tracking changes in the landscape, the environment and the atmosphere. More recently, the images have been made easily accessible via Google Earth.

The Apollo digital image processing technology was also famously used in MRI scanners, although NASA had nothing to do with actually inventing the medical equipment itself. Freeze-drying techniques used to preserve space food passed over into industry, and so too did water purification technology. And the materials developed to protect Apollo astronauts in space and on the surface of the Moon also found their way into everyday life.

## Spacecraft design software is used to prototype rollercoasters

The 1968 computer program, NASTRAN, was originally written to help NASA engineers design spacecraft, but it was released to the public in 1971 and has since been used for a number of different applications. Its ability to test the elastic properties of structures made it perfect for modelling car suspension, bridges and even rollercoasters.



## Space Station robots could build cars

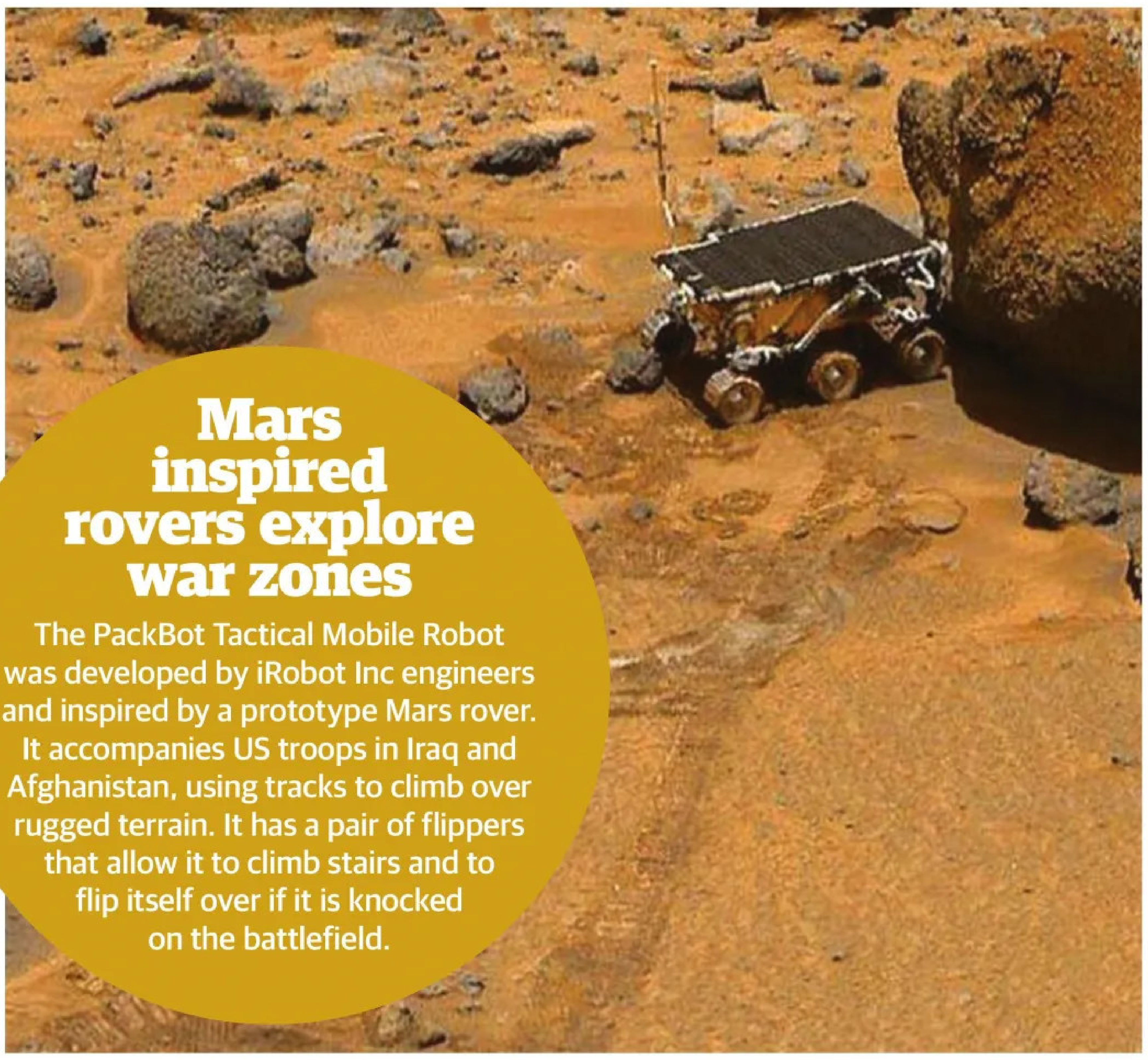
Working with General Motors, NASA has been developing Robonaut 2 (R2): a robotic ISS crew member. It is being designed to be able to work safely alongside people both in space and on Earth. Not only could the technology have uses on the ground in safer manufacturing, but associated products, like exoskeletons and gloves, could have medical uses.

Sports shoes have been made using the techniques behind space boots, and the lightweight, moisture-resistant fibreglass designed for use in spacesuits was used to build the first retractable cover at a National Football League (NFL) stadium. It was strong, but still allowed enough light through to reach the grass on the pitch below. The Apollo life support systems were adapted to form the basis for breathing apparatus to protect firefighters from smoke inhalation, and the suit cooling systems, designed to make the astronauts more comfortable, were adapted for emergency service and medical use.

Even the computer program designed to minimise the power usage of a portable Moon drill found its way back down to Earth, and was later used to create the iconic 1980s cordless vacuum cleaner, the Black and Decker Dustbuster. After this flurry of innovation, NASA set up its Skylab in the 1970s - Skylab was the first American space station. This allowed experiments to be conducted in orbit around the Earth.

Innovations sparked by the Skylab included new techniques for helping newborn babies to breathe, computerised solar water heaters, and self-powering signs that glowed without the need for electricity. which are now used to light the way in emergencies.

The Space Race ended in 1975 when the United States and the Soviet Union teamed up to dock a



## Mars inspired rovers explore war zones

The PackBot Tactical Mobile Robot was developed by iRobot Inc engineers and inspired by a prototype Mars rover. It accompanies US troops in Iraq and Afghanistan, using tracks to climb over rugged terrain. It has a pair of flippers that allow it to climb stairs and to flip itself over if it is knocked on the battlefield.

## Orion technology is protecting deep sea divers

NASA's new Orion spacecraft has only made it off the launchpad for a test flight, but it is already sparked a number of spin off technologies. The company behind Orion's life support have adapted the same systems for use by divers working in extreme and dangerous environments, like toxic spills.

## Infrared satellite technology inspired an in-ear thermometer

Infrared satellite imaging technology, developed at the Jet Propulsion Lab in California for the Infrared Astronomical Satellite was originally designed to measure the temperature of distant stars. In 1991, it was transformed into a thermometer that could measure body temperature using infrared light.

NASA Apollo command module to a Soviet Soyuz 7K-TM. Investment slowed, but it marked a new era in international space exploration, and innovations continued to pour out. Since 1976, NASA has been keeping track of the best innovations in a magazine known as *Spinoff*.

The Space Shuttle missions began in 1981, and required another vast financial investment. A single Space Shuttle launch cost an average of $450 million (£293 million), and each of the 130 or so flights set the space agency back around $1.5 billion (£0.9 million). With this spending came another wave of innovation and, according to NASA, over 100 technology spin-offs. The visors developed for the astronauts on the Space Shuttle programme inspired scratch-resistant reading glasses, and an iodine-based purification system designed to recycle water was adapted for use in disaster relief efforts. LED panels designed to grow plants on board the shuttles have been adapted for medical uses, Space Shuttle shock absorber technology is now being used to protect buildings against earthquakes, and imaging technology developed to measure surface damage on the shuttles can capture and analyse pictures of crime-scene evidence.

At the same time, other NASA projects were also making a difference in the wider world. In 1985, grooved surfaces that NASA had developed to reduce slipping on runways were adapted for use on steps and in car parks to protect pedestrians in the wet. And, later in the same decade, technology used by NASA satellites to study the ozone layer was repurposed to create lasers capable of breaking down blockages in human arteries. In 1990, NASA launched another major mission: the $2.5-billion (£1.6-billion) Hubble Space Telescope. It had an unnoticed fault in its optics and required a heroic (and expensive) repair in order to function properly, but since then it has more than made up for its cost.

Not only has Hubble provided an incredible window out on to the galaxy, its advanced optics and imaging technologies have inspired other industries, providing the basis for improved microsurgery techniques and tumour biopsies, as well as advancements in the manufacture of semiconductors.

The Hubble Space Telescope was followed in 1993 by one of the biggest contributors to scientific and technological advancements made in space – the International Space Station. This orbiting laboratory has been permanently occupied by teams of astronauts and cosmonauts since 2000, and over the course of its lifespan, it has racked up a bill in excess of $100 billion (£6.5 billion) – although NASA is only responsible in part.

The microgravity environment on the Space Station allows unique experiments to be conducted, and data has been gathered in a vast number of fields, from materials science, to biology, to robotics. Superconductors and nanomaterials have been tested on the station, plants and animals have been studied, and the human body has been monitored. Thanks to the International Space Station, we now have a robotic arm that can perform surgery inside a MRI scanner, a new method of delivering cancer-fighting drugs, and even some high-performance golf clubs.

# NASA around you

A great deal of space-inspired innovations can be found in your city and even at home

### 1 Manufacturing

- Powdered lubricants
- Improved welding
- Power plant design
- Smokestack monitors
- Rapid prototyping
- Chemical detection
- Improved mine safety
- Protective cool vests
- Quick fasteners

### 2 Household

- Ingestible toothpaste
- Cosmetics
- Memory metal alloys
- Environmentally safe sewage treatment
- Polished brass finish
- Memory foam mattresses
- Phase-change materials
- Improved footwear
- Water softeners

### 3 Coastal

- Search and rescue at sea
- Flood monitoring
- Environmentally safe ship clearing
- Environmentally safe sewage treatment
- Oceanic monitoring
- Pollution remediation
- Dam corrosion control and bridge support

### 4 Sports & recreation

- Shock-absorbing athletic shoes
- Stadium material
- Plasma displays
- Protective padding
- Golf equipment
- Helmets
- Ingestible thermometers
- Protective cool vests
- Heart rate monitors
- Tennis rackets

### 5 Air travel

- Collision avoidance systems
- Clean-burning engines
- Nitrogen oxide reduction
- Anti-icing systems
- Optics for high-speed ticket processing
- Virtual biofeedback training
- Jet lag prevention
- Cabin pressure devices
- Parachute systems
- Voltage controllers

### 6 Medical

- Light-Emitting Diodes (LEDs)
- ER infrared ear thermometers
- Automatic insulin pumps
- Artificial limbs
- Clean room apparel
- Precision dialysis pumps and fibres
- Invisible braces
- Diamond coatings: artificial hip joints
- Corneal refractive therapy
- Ventricular assist device
- Dental waterline purification cartridge
- Gait analysis system

### 7 Public safety

- Fire-resistant reinforcement
- Video enhancing and analysis systems
- Fire sensors
- Face masks and fire suits
- Land mine removal
- Anthrax detection
- Flame-retardant materials
- Self-illuminating materials
- Lifeshears
- Breathing systems

### 8 Automotive

- Truck design
- Highway safety
- Structural analysis
- Crash analysis
- Car chassis and brake systems
- Advanced lubricants
- Improved radial tyres
- Cleaner burning cars

### 9 Grocery

- Food safety systems
- Enriched baby food
- Packaging and freeze-drying
- Hyperspectral imaging of chicken
- Refrigeration showcase

The technology used to build the Station itself, and the equipment on board, has also been useful back on Earth. The imaging software designed to help robots to assemble the Space Station is now used to analyse the damage to crash test dummies, helping to improve safety in cars, and hand-held warning-systems designed to detect falling pressure in parts of the station are now used to monitor cabin pressure on planes. Back on the ground, NASA continued to pioneer research in other areas. A major focus throughout its history has been understanding contamination and developing clean rooms within which to assemble spacecraft. These innovations have since found their way into medicine, manufacturing and industry.

NASA technology developed to measure the airflow in wind tunnels is now used to monitor the polluting emissions from industrial smokestacks, and colour-changing optical fibres designed to detect dangerous chemicals on aircraft are now being used as a warning system for industrial accidents or chemical warfare.

Precision GPS designed to test Einstein's theory of relativity is being used to drive remote-controlled tractors, and supercomputers normally used to analyse the flow of fuel in rocket engines have been used to design a device that can keep blood flowing through the body while a patient waits for a transplant. Even excess rocket fuel has found a use, providing the basis for 'Demining Device Flares', which destroy landmines by burning away the explosives inside.

NASA has made significant technological advancements that have had a real impact on the everyday lives of people across the world. It continues to push the boundaries of human achievement, including pioneering ambitious and expensive missions to explore our potentially habitable neighbour, Mars.

The 1997 Mars Pathfinder mission along with the 2011 Curiosity rover set the American space agency back by billions of dollars, but the scientific and technological advancements made along the way have been huge – and they don't stop here.

The technology used to weave the tough Pathfinder parachutes has been used to make stab- and impact-resistant vests, and the Mars rovers themselves have been adapted to create reconnaissance robots to seek out explosive devices in war zones. These military rovers can climb steep slopes, function under water and even navigate stairs.

Technology designed to search for water on Mars has been adapted for use on aircraft, allowing them to detect water in the air for weather forecasting, and technology developed to search for life on Mars is being used to monitor for biological threats.

Mineral analysers are being used in pharmaceuticals and forensics, and the techniques used to develop new methods of growing plants in space and on Mars are being adapted for use in other biological experiments, like drug development. The Mars rovers have revealed a planet that could be habitable by humans, and that could even be home to extraterrestrial life, and the technology being prepared for the next phases of exploration is already set to have important uses back on Earth.

### Space Shuttle shock absorbers protect buildings from earthquakes

Shock absorbers designed for use during the launch of NASA's Space Shuttle missions formed the basis for technology that now protects more than 500 buildings in earthquake-prone areas across the world. Known as 'fluidic dampers', the shock absorbers contain oil to absorb the impact.

### Apollo heat shielding protects buildings from fire

The Apollo heat shielding was specifically designed to burn as it reentered the atmosphere, forming a protective layer around the craft. NASA-funded research to apply this technology elsewhere. An adapted version has been used to coat steel frames supporting large buildings.

By 2012, nearly 1,800 different NASA spin-off products had already been catalogued, and this is just the tip of the iceberg. NASA has inspired scientists, engineers, thinkers, inventors and entrepreneurs, and its innovations and scientific advancements contribute to a growing base of human knowledge that will form the platform for advances that we can't even dream about today. NASA may be expensive, but speaking in 1974, science fiction writer and scientist, Isaac Asimov, explained the essential core of the argument, "If we refuse to take those steps because we don't see what the future holds, all we're making certain of is that the future won't exist".

At its inception in 1958, no-one could have predicted the impact that the American space agency would have on space exploration or on science and technology as a whole, but looking back over the last 60 years it becomes clear. When asked what is the good of NASA, Isaac Asimov replied, "The proper answer is: you may never know, but your grandchildren will", and that's turning out to be absolutely true.

### Viking parachute covers make hard-wearing tyres

The two Viking landers were sent to the surface of Mars in the 1970s, and their parachutes needed protection on the journey. The stronger-than-steel fibres designed to protect the Viking descent gear were later incorporated into car tyres by Goodyear, extending their lifespan by thousands of miles.

### Hubble optics tool helps ice skaters at the Olympics

The technology used to create the optics for the Hubble Space Telescope was adapted, in collaboration with the US Olympic Committee, to develop a sharpening tool for ice skate blades. The sharp skates outperformed traditional versions, and were used by Chris Witty when she won gold and set a world record at the 2002 Winter Olympics.

### Things that NASA really didn't invent

- Tang (drink)
- Velcro
- Teflon
- Barcodes
- Quartz clocks
- Smoke detectors
- Cordless power tools
- MRI scanners
- Microchips
- Space pen

@ Adrian Mann; NASA

# HISTORY OF NASA

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# HISTORY OF NASA

THE FASCINATING STORY OF THE ICONIC AMERICAN SPACE AGENCY

America's secret space race

Many early American space projects were shrouded in military secrecy as the US military raced to compete with their rivals in the Soviet Union

## Cold War origins

Discover the catalysts that kick-started the Space Race

APOLLO 11 THE INSIDE STORY

What *really* happened the day we landed on the Moon

"A space mission will never be routine... you're putting three humans on top of an enormous amount of high explosive"

Was Buzz Aldrin meant to be the first man on the Moon?

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Astronauts, cosmonauts and a new era

## A mission of peace

Learn how NASA's philosophy inspires, on Earth and beyond it

CELEBRATING VOYAGER

Over four decades ago, what would become two of NASA's most iconic spacecraft set off on a 'Grand Tour' of the Solar System... and they're still going strong

## Our new frontier

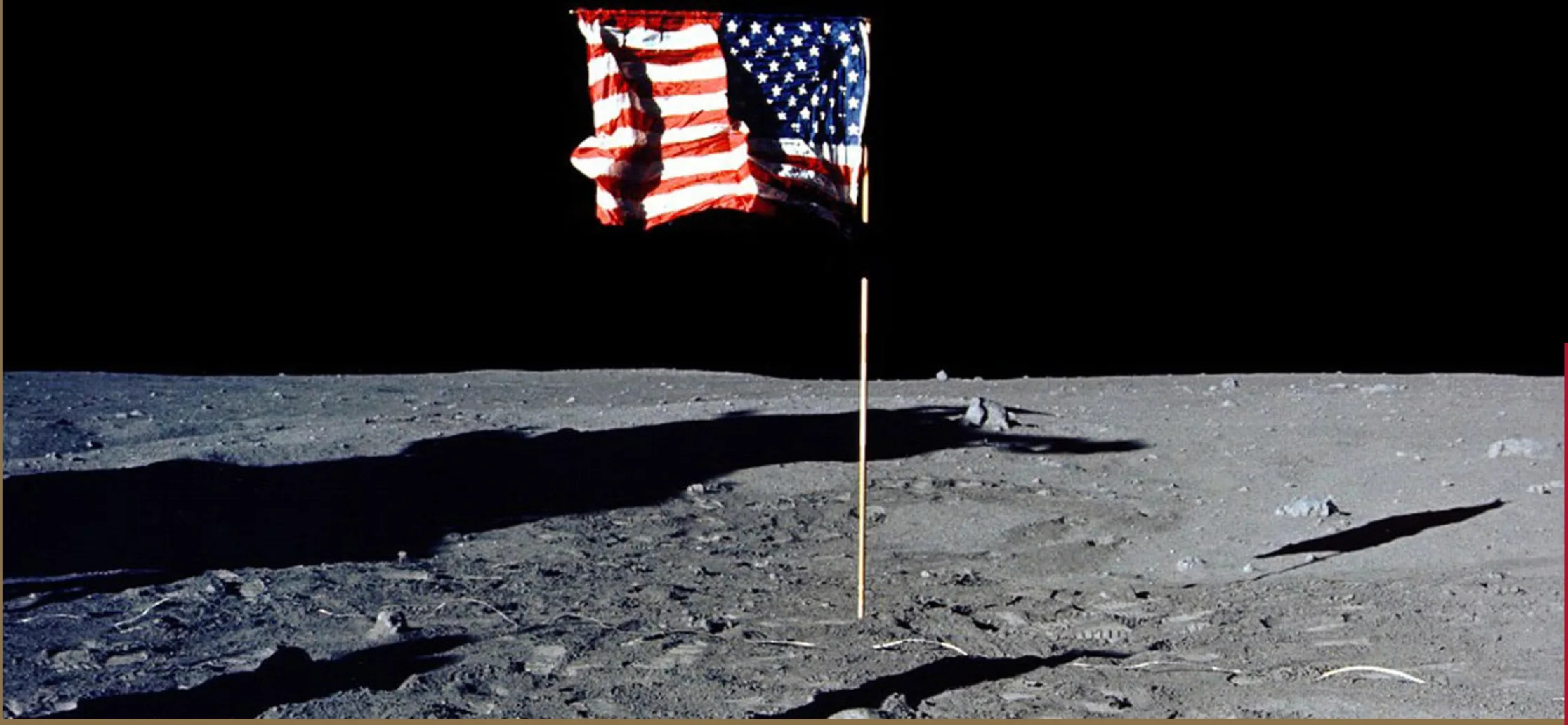
Marvel at the cosmic wonders NASA has discovered and shared

What has NASA done for you?

Hundreds of billions of dollars have been spent on space exploration, but take a look at what we got in return

## Space Age technology

Explore how quests in space have improved our life on Earth



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